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The Story of an Observatory*

(The Fiftieth Anniversary of the Yerkes Observatory)

By OTTO STRUVE

It is useful from time to time to discuss the broader policies of our organization; and the occasion of the 50th anniversary of the Yerkes Observatory presents a convenient time for such a discussion. The men who founded the observatory are no longer living, but their hopes and aspirations are recorded in the pages of their publications in the *Astrophysical Journal* and elsewhere. We can compare these hopes with our actual accomplishments, and perhaps derive some useful lessons for the future.

During the summer of 1892 a young man of 24 was attending a meeting of the American Association for the Advancement of Science at Rochester, New York. One hot evening a group of delegates were sitting in front of the hotel, trying to keep cool. The young man was in a receptive mood and his ears readily caught a tale that the famous Cambridge telescope builder, Alvan G. Clark, was telling to a group about him. It seems that in 1889, when the Lick Observatory was beginning to create its world-wide reputation, the people of Southern California, then in the uproar of a land boom, felt that their fair territory might advantageously profit by the example of James Lick. So a worthy citizen offered to a local educational institution land then valued at fifty thousand dollars. This was ample warrant, in the judgment of the hour, for ordering a pair of 40-inch glass discs, which in the course of three years had been successfully made by M. Mantois in Paris. But unfortunately the land-bubble had meanwhile burst, the gift was worthless, and Mantois was vainly seeking payment of the sixteen thousand dollars at which the discs were valued. Here was a great opportunity, said Clark, for someone to get a large telescope without loss of time. He had tested the glass and found it perfect, and nothing would please him more than to figure a 40-inch objective.

The name of the young man was George Ellery Hale, and this description of the origin of the Yerkes Observatory is quoted, almost verbatim, from an unpublished manuscript which he communicated to the American Astronomical Society when it met here in 1922 to celebrate the twenty-fifth anniversary of this observatory and of the founding of the Society.

*Presented at a staff meeting of the Yerkes Observatory on March 25, 1947.

Mr. Hale had left the Yerkes Observatory long before I arrived in Williams Bay, and now, that Miss Calvert has also gone away to live with her sister in Nashville, there is no one left on our staff who knew him in the days when he created the Yerkes Observatory and formulated its scientific program. I had, however, the pleasure of meeting him at his private Pasadena Observatory, about 20 years ago, when I was spending a summer at Mount Wilson. He was then a man past middle age, of distinguished appearance, but of an almost boyish enthusiasm for the spectroscopic installation which he showed me, and in which, incidentally, he was using the 12-inch photographic objective which once belonged to him at the Kenwood Observatory, in Chicago, and which he had donated to the Yerkes Observatory when he became its first director. He had later borrowed it for his private laboratory in Pasadena. At that time Hale was no longer the director of the Mount Wilson Observatory. Since 1910, when he was in his early forties, he had suffered from a serious physical illness. He was never completely

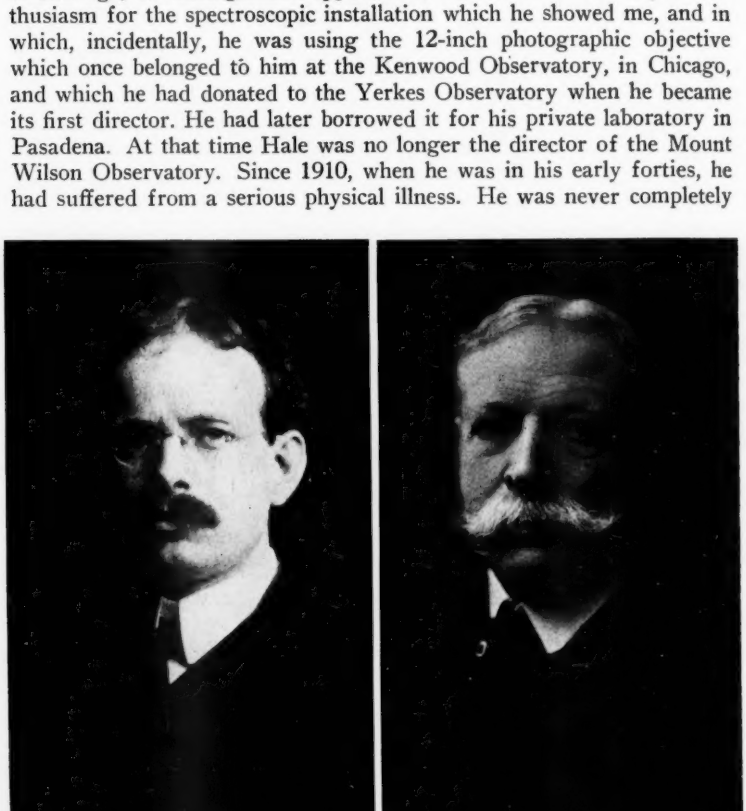

FIGURE 1

GEORGE ELLERY HALE
(1869-1938)

CHARLES T. YERKES
(1837-1905)
(From photograph by
H. Walter Barnett)

free from more or less severe attacks of brain congestion which occasionally produced severe pain and almost complete mental exhaustion. With great perseverance and admirable courage he readjusted his entire life and began to engage in activities which caused less strain upon his nervous system. He built his own private observatory where he engaged in observations with the newly-invented spectrohelioscope, and he devoted much time to the problems of the National Academy of Sciences in Washington, the National Research Council, and the Council of International Scientific Unions. He officially resigned the directorship at Mount Wilson in 1923, and was appointed by the Carnegie Institution as honorary director—a title which he held until his death in 1938.

Hale's early scientific life and development form a most inspiring story. In an obituary article for him his friend, long-time associate and successor at Mount Wilson, Dr. W. S. Adams, has given us the following excerpts from Hale's own biographical notes (*Ap. J.*, **87**, 371, 1938):

"I cannot fix the date of my first interest in astronomy, but it must have been when I was 13 or 14 years old. I built a telescope, but as I used a large single lens, the images were not good. About this time I became acquainted with S. W. Burnham, then a stenographer in the Chicago law courts by day and an ardent observer of double stars by night. Through him I learned of a second-hand Clark refractor, of 4 inches aperture. This was purchased by my father, and I mounted it on the roof of the house. The astonishing views it afforded of Saturn, the moon, Jupiter, and other objects excited an intense desire to carry on actual research. So I attached a plateholder to the telescope and photographed a partial eclipse of the sun. I also began to observe sunspots, and made drawings of them. Thus I became an amateur astronomer.

"At this period the 18½-inch Dearborn refractor stood at the summit of a lofty tower forming part of the old University of Chicago (long since demolished, after the removal of the telescope to the Northwestern University at Evanston). Professor G. W. Hough, known for his observations of Jupiter and double stars, who was in charge of the instrument, was kind enough to let me look through it frequently. I was also permitted to aid the feeble gas-engine in turning the dome, or rather drum, of the observatory. Naturally, my own ambitions were thus stimulated, but neither Hough nor Burnham had the slightest interest in astrophysical research and I could not have devoted my life to such work as they were doing, valuable as it was to science. The reason lay in the fact that I was born an experimentalist, and I was bound to find the way of combining physics and chemistry with astronomy. Fortunately, it was not far to seek.

"In Cassell's book is a description of a spectroscope, with an account of the construction of a simple instrument, using either a luster prism

or a hollow one fitted with carbon disulphide. I built both forms, and the odor of the disulphide abides with me after a lapse of 50 years. Then my father, always ready to encourage serious efforts, enabled me to buy a small spectrometer. This had a single prism, and I lost no time in fitting it with a small plane grating. For by this time I had learned of the work of Rutherfurd and Rowland and had acquired some slight conception of the possibilities of high dispersion. Nothing could exceed my enthusiasm in observing the solar spectrum and in measuring the principal lines. I bought Lockyer's "Studies in Spectrum Analysis" and began the observation of flame and spark spectra and their comparison with the spectrum of the sun. At last I had found my true course, and I have held to it ever since."

In 1892 Hale was filled with the exuberance of youth. He had visually observed the solar prominences with a spectroscope at the Kenwood Observatory and he was filled with a simple, but very strong ambition: he must find a way to photograph the prominences without an eclipse. This ambition was gratified when he invented the spectroheliograph. With this new instrument he discovered the large mottled areas in the light of the calcium lines H and K which we call flocculi, and which represent, essentially, those solar prominences which are seen projected upon the disc of the sun. He keenly felt the inadequacy for further study of the flocculi and prominences of his own 12-inch telescope at Kenwood and he determined that he must have a larger telescope.

The opportunity came soon after he had overheard the conversation of Alvan Clark at Rochester. At the suggestion of Mr. Charles Hutchinson of Chicago, the same man who has done so much for Chicago's Art Institute, and for the University of Chicago, Mr. Hale approached Mr. Charles T. Yerkes who had expressed an interest in the then new and struggling educational venture which was the University of Chicago under President Harper. Mr. Yerkes invited the latter, together with Mr. Hale, to call upon him in his downtown Chicago office, and before the interview was over a telegram had been drafted to Mr. Clark to come to Chicago with a contract for the two lenses.

At first Mr. Yerkes consented only to purchase the objective. There were no funds for the mounting, the dome or the building. Mr. Harper was reluctant to divert any of the University's limited funds for the observatory, and Mr. Yerkes undoubtedly thought that Mr. Rockefeller's millions should build, equip, and maintain the observatory he had initiated. After several long years of nerve-racking uncertainty this financial problem was solved through the further generosity of Mr. Yerkes. Plans were drawn up in 1894 and construction of the building, as we now know it, was begun in 1895.

In the preceding year Mr. Hale had given careful attention to the choice of a suitable site for the great telescope. The extreme care with which he approached this question is evident in an article in the *Astro-*

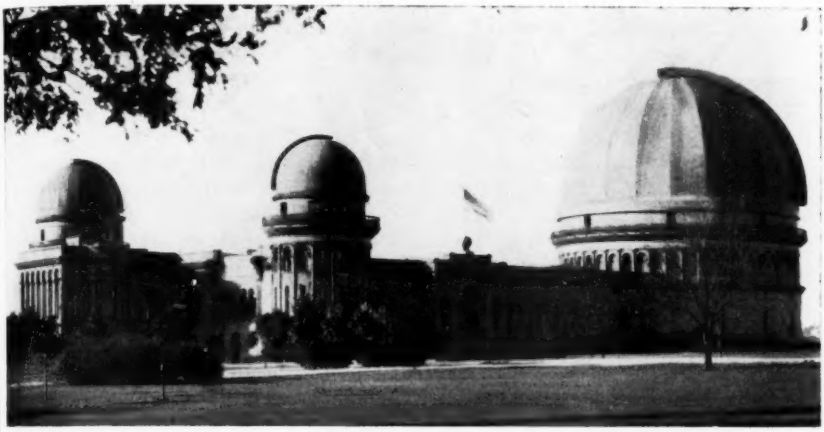

FIGURE 2
THE YERKES OBSERVATORY FROM THE NORTHEAST.

physical Journal for 1897 in which he summarized the principal questions, the answers by leading American and foreign astronomers, and his own final conclusions. For example, the question of a mountain site was answered negatively because of the unfavorable day-time seeing which Hale himself had witnessed on Pikes Peak and other points in the Rocky Mountains; the maximum distance at which "a city like Chicago would appreciably affect observations with a 40-inch refractor" was estimated at not less than ten miles from its boundaries, but allowance was to be made for the future growth of the city. The vicinity of a large body of water like that of Lake Michigan was to be avoided because of greater cloudiness; there was some disagreement among the astronomers as to whether the presence of water improved the seeing or made it worse. The final choice fell upon a location at Williams Bay, Wisconsin, on the northern shore of Lake Geneva. The opinion of Professor Burnham, who had taken an active part in choosing the site of the Lick Observatory, was taken as final.

In the meantime the Warner and Swasey Company had completed the mounting and exhibited it at the Columbian Exposition at Chicago in 1893. The grinding and polishing of the objective took much longer. It was only in October of 1895 that the two lenses were finished and tested by Mr. Keeler and Mr. Hale. The quality of the star images was found to be excellent. Then there followed a long delay in building the observatory. Finally, on May 19, 1897, the lenses arrived in Williams Bay and two days later, after they had been mounted in the great tube, the first observations were made by Hale, Barnard, and Ellerman. Although the seeing was not very good many objects were

well seen, notably the ring nebula in Lyra, the globular star cluster in Hercules, and the dumbbell nebula. The great light-gathering power of the telescope was well illustrated by the fact that Professor Barnard saw these objects better than he had ever seen them at Mount Hamilton. He also succeeded in finding a new optical companion of Vega which had not been seen elsewhere.

Then in the morning of May 29, only a little more than one week after the beginning of the observations, a cable slipped from its fastening and the entire south side of the rising floor crashed to the ground from a height of 45 feet. Fortunately, there were no observers on the floor when the accident occurred. Mr. Barnard and Mr. Ellerman, who had been working throughout the preceding night, had gone home at dawn. The telescope must have been severely jarred during the collapse of the floor. It took a long time to reach the objective—at first there were thought to be indications of fine fissures in the glass. Only later was it established that a fine cobweb built in the large tube by a spider had given rise to the peculiar design which looked like fissures. The lens was undamaged. But it took several months for the Warner and Swasey Company to rebuild the floor, and the dedication, at first scheduled for October 1, had to be postponed until October 18.

Although Mr. Hale's own work depended primarily upon the completion of the 40-inch refractor, he had from the very beginning intended to add to the equipment a reflecting telescope of 60-inch aperture. A glass disc was purchased by Mr. Hale's father, and optical work on the mirror was soon started in the optical shop of the Yerkes Observatory by G. W. Ritchey. The gift of the mirror by the elder Hale was conditioned upon the University of Chicago being able to raise the necessary funds for the mounting and dome. However, it soon became evident that the University was in no position to undertake additional financial burdens, and Mr. Hale began to look elsewhere for support. His published and unpublished statements, as well as his letters, show a growing concern over financial matters. The observatory had started functioning with an almost ridiculously small staff. Burnham and Barnard came from the Lick Observatory as senior astronomers, F. L. O. Wadsworth was appointed as theoretical physicist, Ritchey came as optician, F. Ellerman and S. B. Barrett filled the two assistantships. W. H. Wright was a fellow and as such determined the geographical coordinates of the observatory.

Because of the heavy financial restrictions, Mr. Hale was obliged to guarantee that the operating expenses would not exceed a very small sum during the first year, and this meant that additional money to pay the salaries had to be raised from other sources. In this emergency the Carnegie Institution of Washington came to the rescue. A special grant from the same source brought to the Yerkes Observatory Mr. Frank Schlesinger whose work on the photographic determination of stellar

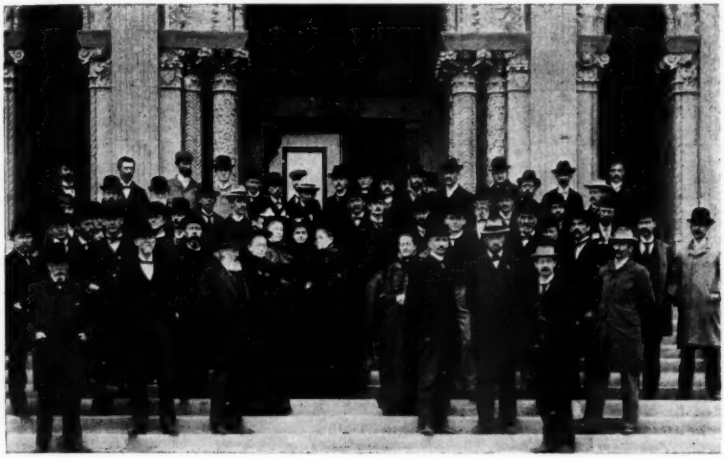

FIGURE 3
PHOTOGRAPH OF PERSONS ATTENDING THE DEDICATION ON OCTOBER 18, 1897.

1. E. E. Barnard
2. C. H. Rockwell
3. George F. Hull
4. Colton (?)
5. Kurt Laves
6. Frank W. Very
7. E. B. Frost
8. Henry M. Paul
9. Ernest Fox Nichols
10. F. R. Moulton (?)
11. Ephraim Miller
12. Father John Hedrick
13. John M. VanVleck
14. Milton Updegraff
15. William R. Brooks
16. F. L. O. Wadsworth
17. H. C. Lord
18. F. H. Seares
19. George W. Hough
20. W. H. Collins
21. Caroline E. Furness
22. Mrs. Pickering
23. Mrs. Hale
24. Miss Cunningham
25. Alva A. Lyon
26. Carl A. R. Lundin
27. J. A. Parkhurst
28. John A. Brashear
29. G. W. Ritchey
30. C. H. McLeod
31. Father J. G. Hagen
32. Charles Lane Poor
33. J. K. Rees
34. Miss Mary W. Whitney
35. F. P. Leavenworth
36. Henry S. Pritchett
37. James E. Keeler
38. A. G. Stillhamer
39. Hugh L. Callendar
40. George W. Myers
41. Charles L. Doolittle
42. E. C. Pickering
43. A. W. Quimby
44. Asaph Hall
45. Albert S. Flint
46. M. B. Snyder
47. W. W. Payne
48. Carl Runge
49. Winslow Upton
50. George Kathan
51. G. D. Swezey
52. George E. Hale
53. N. E. Bennett
54. George C. Mors
55. F. Ellerman
56. W. J. Humphreys
57. Henry Crew

Identifications made about January 1, 1923, by F. Ellerman, E. E. Barnard, S. B. Barrett, J. A. Parkhurst.

distances became one of the principal contributions to astronomy of the Yerkes Observatory.

The regular staff was enlarged in 1898 through a gift by Miss Cath-

erine Bruce of New York which enabled Mr. Hale to invite as professor of astrophysics Dr. Edwin B. Frost of Dartmouth College at Hanover, N. H. The latter was soon joined at Williams Bay by his former pupil, Dr. W. S. Adams. Together these two men started an ambitious program of radial-velocity determinations of early-type stars—a work which led to the recognition of the so-called K-term in the motions of the stars.

During the first years of the life of the Yerkes Observatory Hale's inspiration dominated the entire staff. His papers filled the issues of the *Astrophysical Journal*—mostly with notes enlarging upon his work on the flocculi of the sun, on the emission lines of the chromosphere, etc. At the same time Hale undertook a far-reaching study of the spectra of late-type stars, in cooperation with Ellerman and Parkhurst. They used the old Brashear spectrograph of the 40-inch refractor, an instrument since dismantled. But some of the results, such as the violet spectra of such famous N-type stars as 19 Piscium, have remained unsurpassed until a few weeks ago!

Hale's program had started out with the simple wish to observe the prominences and flocculi with a large telescope. By the time of the official dedication of the Yerkes Observatory, in October, 1897, his ideas had crystallized into a remarkably logical and comprehensive plan of research. The fundamental purpose of the Observatory was to serve as a center for the coordination of research in astronomy and in physics. To bring this about there was to be a modern spectroscopic laboratory, as well as optical and mechanical shops. But Hale recognized that it was not possible to draw a rigid line between astrophysics and positional astronomy, and through the appointment of Barnard and Burnham he at once gave recognition to the demands of classical astronomy. The 40-inch telescope surpassed all other instruments then in actual operation in focal length and in light-gathering power. It must be used to the best advantage in those branches of astronomy where high resolving power and concentration of light are important. Hale gave several illuminating examples of the manner in which he proposed to carry on his work. Suppose, he said, that an absorption line in a sunspot could be definitely identified and suppose that it would show a displacement in wave length. The observer would know that there are two causes which can produce such a shift: motion in the line of sight and the effect of pressure. In the past the astronomer would have been content with announcing the observed shift, in the hope that perhaps years later some physicist might accidentally find the announcement and test it in the laboratory. Now, with a physical laboratory as an integral part of the Observatory the observer would immediately test the pressure shift of the line under consideration and thereby preserve time, energy, and above all his own interest in the problem.

Hale was convinced of the enormous advantages of large telescopes

in astronomical research. In his famous book "The Study of Stellar Evolution" (published in 1908 as Volume X of the second series of the Decennial Publications of the University of Chicago) he said: "To those who have used both large and small telescopes, the great advantages of large instruments for many kinds of work are well known. I have heard a European astronomer exclaim, when looking at Jupiter

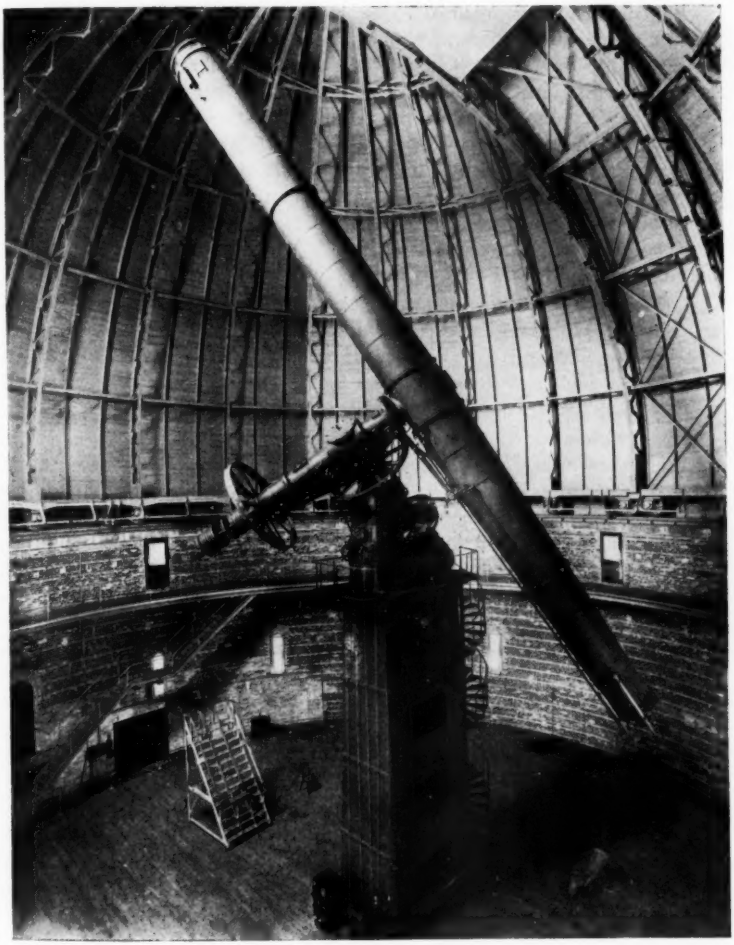

FIGURE 4

THE 40-INCH REFRACTOR OF THE YERKES OBSERVATORY WITH MOVABLE FLOOR NEAR ITS LOWEST POINT.

for the first time with the forty-inch Yerkes telescope, that his years of study of this planet with a small telescope seemed almost useless, so much more detail could be perceived at a single glance. I have seen minute structure on the Moon with this telescope, no trace of which could be made out with a twelve-inch telescope on the same evening. Countless fine bright lines in the spectrum of the chromosphere, which could never be detected with the 12-inch, are easily seen with the 40-inch. Burnham has separated double stars at the theoretical limit of resolution of the Yerkes telescope, and Barnard has observed the tiny fifth satellite of Jupiter when it was beyond the reach of all but the largest existing instruments. When I think of these observations and of Ritchey's photographs of the Moon and star clusters, Frost's and Adams' photographs of the spectra of faint stars, and the no less important results obtained by Schlesinger, Parkhurst, Ellerman, Fox, and others with the Yerkes telescope, and when I remember that most of these observations or results could not have been obtained with a small telescope, I see no possible reason for denying the manifold advantages of large instruments."

Those of us who have had occasion to make visual observations with the 82-inch McDonald telescope will agree with me that on nights of good seeing the gain in visibility of details on the Moon and planets over the 40-inch is at least as great as the gain described by Mr. Hale of the 40-inch over the Kenwood 12-inch.

Mr. Hale's own work, during the first seven years, was spread over an enormous area. His most important contributions continued to be those in solar physics. In 1902 he announced the existence of large areas on the sun whose absorption spectra differed markedly from the normal solar spectrum. "Every spectroscopist will understand" he wrote, "why I have hesitated to publish these spectra. So far as I know, the phenomenon is quite without precedent, and I could hardly believe it possible that the solar spectrum should undergo so complete a change throughout an area whose length was at least one-eighth of the Sun's diameter. Had the disturbance been confined to the spot it would have seemed far less remarkable, though even then without precedent; but the photographs show it to extend far beyond the spot, with few, if any indications that the width of the spectrum was sufficient to include the entire disturbed area."

If we should now try to evaluate the results obtained at the Yerkes Observatory during the first half of its life we should probably agree that while Hale furnished the stimulus and paved the way, it was the work of others that actually brought in the most important results. In order of significance, as they impress me today, these results are the following:

1. Barnard's photographic work with portrait lenses which culminated in his own and in Ross' magnificent atlases of the Milky Way.

Barnard was trained in his youth as a photographer, and it was quite natural for him to try different commercial lenses in the photography of the night sky. Together with Max Wolf he shares the claim to priority in this field. Barnard always retained an artistic interest in his work: the beauty and intricacy of form of the star clouds and nebulae fascinated him and he was constantly trying to bring out new detail of structure or illumination. The great advance by Ross consisted in his design of a new wide-angle lens which for many years became the most important wide-angle objective in astronomical practice. Ross was primarily a theoretical optician and his work in the photography of the Milky Way was an illustration of the power of his lens.

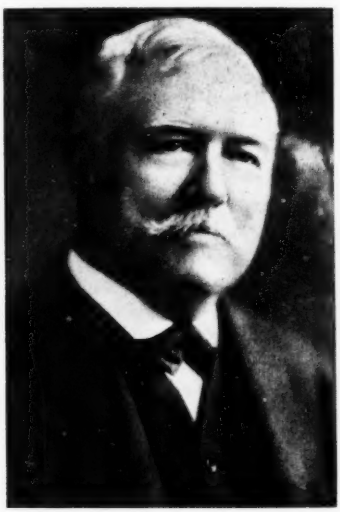

FIGURE 5

EDWARD EMERSON BARNARD
(1857-1923)
(Photograph by Harris and Ewing in 1917)

FRANK SCHLESINGER
(1871-1943)

2. Schlesinger's work on stellar parallax and its continuation by Mitchell, Slocum, Fox, Lee, Moffitt and many others. In an appraisal of the work of American astronomers several years ago the contributions of Frank Schlesinger were accorded first place, and among them his parallax work at Yerkes ranked at the very top. It is difficult now to recognize what an enormous improvement the photographic procedure of Schlesinger meant at a time when parallax work had been done almost wholly visually. The precision was increased by a factor of about 10, and the efficiency of the work was stepped up by at least

another factor of 10. In 1899, Schlesinger published a short paper in the *Astrophysical Journal* calling attention to the fact that not more than 25 or 30 parallaxes were then known to within 0".05, and recommending that the 40-inch telescope be used for photographic measurements. His own connection with the Yerkes Observatory lasted from May, 1903, until March, 1905. In this short interval he determined 26 new parallaxes with an average probable error of $\pm$ 0".013.

3. Frost's and Adams' measurements of radial velocities of B-type stars, the discovery of the K-effect, and the recognition of the slow peculiar motions of the helium stars.

4. Burnham's, and later Van Biesbroeck's, systematic visual observations of double stars.

5. A. A. Michelson's experiments with an interferometer (first conducted by him at the Lick Observatory where the satellites of Jupiter were measured, and then continued at Yerkes, where double stars were measured) and, later, his measurement, with Henry G. Gale, of the earth-tides. The pits in which the ends of the long pipes of water were brought in contact with the interferometer, were located north of the observatory and east of the main drive. For many years they stood abandoned and their cave-like interiors fascinated the minds of a younger generation of astronomers. When I arrived in Williams Bay the darkrooms were still full of exposed film showing the regular pattern of the interferometer as the shape of the earth underwent its tidal deformations. The theoretical determination of the rigidity of the earth was carried out by Dr. F. R. Moulton, professor of theoretical astronomy at the University of Chicago, and the whole project may well be regarded as one of the finest examples of cooperative research in America.

6. Nichols' first successful measurement in 1899 of the heat radiation of Arcturus and Vega, with a radiometer mounted in the heliostat room of the Yerkes Observatory.

7. Ritchey's superb photographs of nebulae, clusters, and other objects, with the 24-inch reflector and the 40-inch refractor. Mr. Ritchey came to Williams Bay as an optical expert. He made the 24-inch mirror and tested it. One of the few serious accidents which we have had occurred soon after this mirror had been completed. On one occasion, when it was being lifted from its cell for the purpose of silvering, it was dropped and broken. Fortunately, Mr. Ritchey was then still at Yerkes, and was able to make a new mirror. It is this second mirror which we are still using. Mr. Ritchey was, like Mr. Barnard, an artist at heart. He took endless pains with his exposures, and in order to bring out the faintest detail he sometimes used such hightly diluted developer that the treatment of the plates in the darkroom occupied many hours. In quality his photographs with the 24-inch have never

been quite equalled. Mr. Ritchey was said to have been somewhat careless about keeping records of these exposures. He would sometimes forget to take his record book with him to the dome, and would then make the necessary entries on the white paint of the door. This did not meet with the approval of the observatory carpenter, who one day decided to plane off the door and restore it to its original gleaming whiteness. In this manner we have lost the records of some of our most valuable photographs: We only know that they were taken by Mr. Ritchey during the term of his appointment at Williams Bay.

These accomplishments, and many others, at once created for the Yerkes Observatory an enviable reputation. But from the vantage point of 50 years later we cannot escape the conclusion that Hale's own tremendous energy was being dissipated among innumerable projects and that his own scientific brilliance was being expended in administrative functions.

Illness in his family added to the complications, and Hale was forced to spend the winter of 1903-04 in California. Professor Frost was appointed acting director, and the director's residence at Williams Bay was leased by President Harper of the University of Chicago, and his family. Mr. Harper was a great organizer and a great scholar, but it seems incongruous that so soon after the dedication of the observatory the principal residence on the hill and the principal office in the main building should be devoted to the study of linguistics.

It is not clear to me whether Hale expected to return permanently to Williams Bay. The Carnegie Institution had provided him with funds for a temporary expedition to Mount Wilson for solar research, and gradually the expedition began to take on a permanent character. There was a long and somewhat bitter exchange of letters between him and Mr. Harper. But in the end Mr. Hale remained at Mount Wilson and took with him some of the ablest members of the Yerkes staff, notably Messrs. Adams, Ellerman, Pease, and Ritchey. The horizontal snow telescope for solar research and the unfinished 60-inch parabolic mirrors were transferred to Mount Wilson. Mr. Frost was appointed director in 1905, but for many years afterwards Mr. Hale was considered a non-resident professor of astrophysics in the University of Chicago.

The period of Mr. Frost's administration, 1905-1932, I can best describe as a period of retrenchment. The loss of the staff was a serious blow, but the gradual transfer of the financial support by the Carnegie Institution from Yerkes to Mount Wilson was even worse. The University, under Presidents Judson and Burton, was dedicated to a program of rigid economy.

During this period the routine programs were carefully continued: new parallaxes were announced from time to time in the quarto publications of the observatory. Two nights each week were assigned to

stellar spectroscopy, and gradually a magnificent collection of stellar spectra, principally of the early types, was gathered by Barrett, Lee, and others. Van Biesbroeck started a program of positional observations of comets and asteroids with the 24-inch reflector, Parkhurst continued to perfect the photometric scales of stellar magnitudes, while Barnard observed with unflagging perseverance all astronomical phenomena that would come to his attention.

In an account of the first fifty years of the Lick Observatory Dr. J. H. Moore recently stated that the most versatile and inspiring of the early astronomers on Mount Hamilton was E. E. Barnard. There can be no doubt that he carried this distinction with him when he came to Williams Bay. Barnard was an ideal observer. He knew and valued the 40-inch and he regarded it as a rare privilege to work with it. To those of us who knew him he was a source of constant inspiration. From him we learned the importance of catching the rare moments of good seeing, from him also we learned that to accomplish something in observational astronomy we must make use of all clear sky: there is not enough of it to waste by starting late or by being too choosy about the conditions. Barnard was always on duty and no sooner would the sky clear up after a snow storm than we would hear him opening the dome. It was a familiar sight for us when Mr. Barnard would walk up in the afternoon to the barograph in the library and would sigh deeply and disconsolately if the pressure was going down. After his death there was a marked decrease in the number of observing hours recorded with the 40-inch telescope: no other staff member could approach him in efficiency and in a constant desire to make use of every bit of clear sky.

I suppose that the most important single contribution of Mr. Barnard was his "Atlas of the Milky Way," and his exquisite series of photographs of bright comets, such as Halley's in 1910 or Morehouse's in 1908. But his influence was perhaps greatest through the fact that he observed virtually everything that could be measured with the micrometer or photographed on a plate. His interest was universal and ranged from such phenomena as the Gegenschein which he had discovered independently of other observers, and of which he had made the most complete series of visual observations on record, to such remarkable objects as the faint star in Ophiuchus which he found, in 1916, to possess the greatest known proper motion—10″.3 per year. The list of his published papers includes more than 900 items, without being complete, and even today there are preserved in his notebooks countless unpublished observations.

The most characteristic feature in the life of Professor Frost was the international scope of his scientific interests. He was a typical New Englander, having been born, in 1866, at Brattleboro, Vermont, and having been trained primarily at Dartmouth College, in Hanover, New

Hampshire. A member of an old and distinguished family, he spent several years, after his graduation from Dartmouth, in Germany under Vogel and Scheiner, and in England with Sir William Huggins. He met Mr. Hale, soon after his return from Europe, at the same auspicious meeting of the AAAS in Rochester, which led to the construction of the 40-inch telescope, and the two men became close friends. Frost had done outstanding spectroscopic work at Potsdam. The directorship of the Shattuck Observatory at Dartmouth had little to offer to a man of his inclinations, while the Yerkes Observatory was badly in need of a competent stellar spectroscopist. With Hale's ability to find money for salaries if he needed it the conclusion was foregone: Frost accepted an offer to come to Williams Bay. His first task was to design and build a new stellar spectrograph from funds donated by Miss Catherine Bruce. The Bruce spectrograph was placed in operation late in 1901. With only minor changes it has served us through more than 45 years —a record that may not easily be repeated!

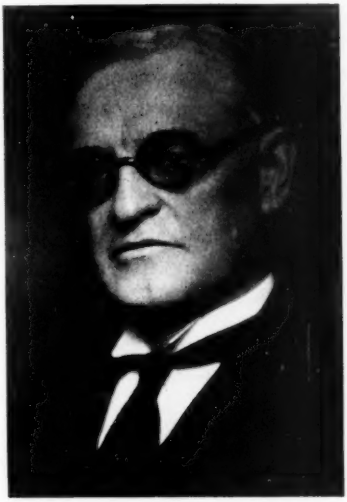

FIGURE 6
EDWIN BRANT FROST
(1865-1935)

Mr. Frost's own interests were mostly in the field of stellar spectroscopy. But he was not a narrow specialist. He was interested in all aspects of astronomy and natural science, and he liked to discuss philosophical and religious questions. His little booklet "The Heavens are Telling" written in 1924 for the American Institute of Sacred Literature went through many editions and was distributed in tens of thous-

ands of copies. His most productive scientific years were in the beginning of his career at Yerkes. As he gradually became more and more absorbed in administrative duties his interest for individual research gave way to a more general interest of explaining nature to others. He was especially fond of children and it was no accident that his last published work was an astronomy for children—a book which had its origin in the many friendly chats which he used to have with the children of his friends and associates.

Incidentally, to Mr. Frost's influence we owe what I might call the tone of this observatory. Every institution has a definite tone; you usually sense it when you enter its doors, and you find yourself acting in accordance with it whether you want to or not. The tone of the Yerkes Observatory, according to outsiders, has always been one of slightly restrained dignity. I have no doubt that this intangible asset is a heritage from the intellectual Vermont background of Mr. Frost. The backslapping kind of joviality was as foreign to him as the exaggerated politeness of the European universities with their long strings of academic titles or their little red or pink lapel ribbons. I never knew Mr. Frost to omit the word Mister when he addressed a man in the observatory, no matter how humble his status.

In the fall of 1931 Professor Frost underwent a serious operation at Billings Hospital in Chicago, and during his absence I was appointed assistant director. I had only a short time before that been promoted to an associate professorship and was therefore greatly surprised when a letter from Dean Henry G. Gale informed me of this action on the part of the University's Board of Trustees. The last years of Mr. Frost's administration were sad ones. His eyesight had failed in 1921 and he was dependent upon his secretary, his friends, and members of his family for all contact with the outside world. Those who knew him in his years of blindness will forever retain in their hearts a vision of the superb courage with which he faced his affliction. Never did he complain or show annoyance. Making use of his phenomenal memory he set himself to memorize the number of steps on the stairways of the observatory, the distances and directions from his house to various convenient landmarks, such as trees, fences, crossings, etc., which he could locate with his cane. Once or twice he lost his way on the snow covered grounds of the observatory. Instead of becoming worried or calling for help, he stood motionless, when he was found, trying to reason out the topological problem of his surroundings. I have seen him in the 40-inch telescope dome hit his head against the heavy counter-weight which is at a man's height when the floor is at its top position and the instrument is pointed due north. He accepted all inconveniences with a smile and a slightly apologetic attitude. But he could not read the scientific literature, and his efforts to keep up with it by having it read to him were not sufficient. His memory enabled him to retain what he had read in

earlier years. It was to me always a source of amazement that he could direct me to the correct page and paragraph of an article in the *Astrophysical Journal* or in Young's "Manual of Astronomy," or that he would remember the details of a sheet of radial-velocity measurements of long ago.

But the struggle was slowly exhausting him. For years he continued to come to my office every morning to learn which stars had been observed with the spectrograph and what the plates had revealed. He himself had not observed since about 1915, and his interests lay in those problems which had been in the foreground at that time. He once remarked that he could not think of a more interesting and exciting activity for an astronomer than the measurement of the radial velocities of the stars. In this field he had been one of the great pioneers and his mind would turn to the days when he found the 4-hour variation of velocity in β Cephei or the systematic motion of expansion of the brighter helium stars.

The years after 1910 and especially after 1920 had brought an enormous development in the field of stellar spectroscopy. The Mount Wilson 60-inch and 100-inch reflectors and the Victoria 72-inch had opened new vistas. New and greatly improved spectrographs were in operation at Lick and Allegheny, and, most important, new men with training in the then new theory of the Bohr atom and in Saha's theory of ionization were at work at some of these institutions.

By the time I arrived at Williams Bay we were hopelessly outdistanced in astrophysics. Our old spectrograph—the gift of Miss Catherine Bruce in 1901—was equipped with badly-annealed prisms of a notoriously opaque and dense Jena flint glass. We had only one moderately satisfactory camera with which we exposed one hour to obtain the spectrum of a 5th magnitude star. With similar dispersion and similar plates we now expose about 15 or 20 seconds at the McDonald Observatory. Our effective limit for spectrographic work was magnitude 5.5, while with the 36-inch Lick refractor equally good radial-velocity measurements could be made to magnitude 8, and Mount Wilson could easily go beyond magnitude 10.

In other fields of astronomy we were also surpassed by others. Hale had intended to use the 40-inch for observations of solar prominences and flocculi. When I met him in Pasadena he told me that the day-time seeing at Yerkes was on the average better than at Mount Wilson and the great aperture of the 40-inch lens was an important advantage in the case of faint prominences, as compared to the relatively small-aperture lenses used in most solar towers. But the Rumford spectroheliograph was old-fashioned and no longer satisfactory. It made use of lenses which Mr. Hale had happened to find for sale, not of lenses especially designed for the instrument. The stray light from reflections on the lenses was very strong and could not be removed by means of

occulting devices; and the definition of the entire spectrum was not as good as that of more modern instruments.

Nevertheless, for many years routine observations with the spectroheliograph were continued, and occasionally they produced some startling results such as pictures of the great prominences which have become standard illustrations in astronomical textbooks. But the great mass of these observations remained unused.

In the field of direct photography Schlesinger's parallax program was continued by a long line of distinguished astronomers, and the results have played an important, but not a decisive, part in formulating our understanding of the stellar system. The 40-inch telescope is corrected for visual light, and a yellow filter must be used in front of the photographic plate to remove the out-of-focus radiations in the blue and violet regions of the spectrum. Hence, the exposure times are very long, and we cannot compete in quantity or in limiting magnitude with the Allegheny Observatory which uses a 30-inch photographic refractor, or with the Mount Wilson Observatory which uses its large reflectors. It is even more disconcerting that despite the great focal length of the 40-inch the precision of the Yerkes parallaxes is no better than that obtained elsewhere with telescopes only one-half as large. The question why this is so has never been satisfactorily answered. It should pose a challenge to those who now continue the work of Schlesinger and his successors.

The 40-inch telescope remained supreme in double star work and the observatory continued to make important contributions in the wide-angle photography of the Milky Way. In the former, our frequent bad seeing at night was a disadvantage. In the latter, requirements of high transparency made it necessary for the observers to secure a large part of their material at Mount Wilson or Flagstaff.

(To be continued)

Physical Characteristics of Sun-Spots

By H. B. RUMRILL

Regarded visually, at an actual distance of less than the sixty thousandth part of a light year—and its further virtual reduction by means of the modern magic carpet of the telescope—sun-spots present such a broad range of appearance and development as to warrant the assertion that no two spots or spot groups are ever precisely alike. With reference to the life history of spots, Young remarks that "almost every one has its own idiosyncrasies," adding that "spots of unusual magnitude and activity often seem to have no quiet middle life; there is no time in their history when they are not doing something or other surprising, and more or less unprecedented."[1]

Similarly with the equally ephemeral phenomena of the faculae, or "little torches" that outshine the brightness of the snow-white photosphere, which are of varied brilliancy, form, and area; often displaying a most wonderful background (or foreground?) of close relationship or association with the spots.

Viewed, however, in a merely casual way, versus the continuous study that is requisite to a better understanding of what is going on below the Sun's photospheric surface, the spot depressions or apertures, whatever their size, are sufficiently like one another to permit generalization of numerous well-marked characteristics, palpable in day-by-day observation. One's first look at the majestic face of the Sun, through a good telescope, with the spots scattered here and there in groupings like constellations of diversified extent and arrangement, gives the impression of independent material bodies rather than of openings through which the darkness underlying the photosphere be-

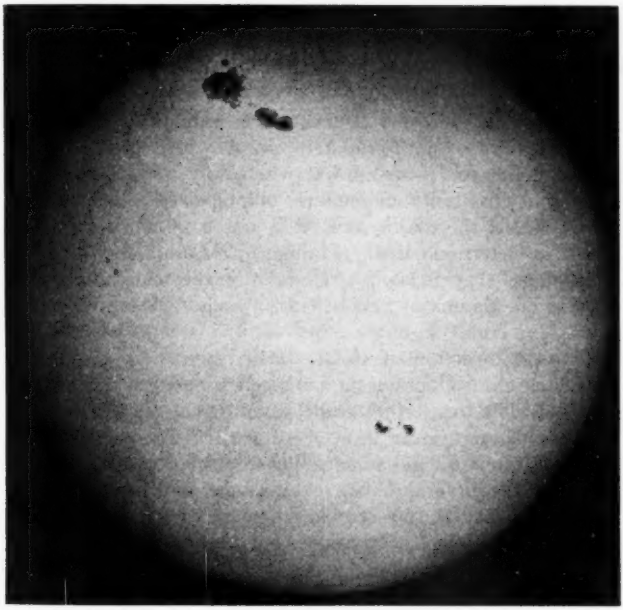

FIGURE 1
PHOTOGRAPH OF THE SUN, FEBRUARY 2, 1946
BY THE REV. WM. KEARONS

The largest spot ever photographed. The area of the great group was approximately five billion square miles, allowing for "foreshortening," or about 1/230 of the hemispherical area. On the same scale the Earth would be represented by a circle 1/32-inch diameter. (The spot at extreme left is considerably larger than the Earth.)

comes evident, as with Herschel's "ein Loch im Himmel."[2]

The subject cannot of course be treated without some reiteration or repetition of the work of the past, which is unavoidable in any attempt at summation of the knowledge accumulated through many years of application by eminent students of the Sun.

The term "spots," which superseded that of "maculae" (the latter conforming with "faculae"), while having the same meaning as its Latin forbear, seems less dignified and appropriate. Notwithstanding its acceptation in astronomical literature, one could wish for a name better suited to the grandeur of this outstanding feature of the Sun's thick envelope of light,—something that might not be taken to imply a blemish or flaw on what was once thought to be an im*maculate* (*i.e.*, unsullied) surface. As respects terminology, I might suggest that the renewed adoption of the Latin *maculae* for these sable chasms in the photosphere needs no argument *in extenso* as agreeing with the other long-accepted Latin words facula, nucleus, umbra, and penumbra; the benefits of uniformity being obvious, as with other usages in the realm of science, and which owe their recognition in part because of avoiding the differences and discrepancies in modern languages.

As to the shapes of the maculae, these exhibit much irregularity, although commonly of approximately circular formation. The smaller ones appear to be well rounded, but when duly magnified show many deviations from circularity. Sometimes oblong or elliptic, with variants in the direction of the major axis, it is not easy when they are near either limb to determine their genuine forms, due to the agency of "foreshortening," that makes a circle take on the semblance of an oval. In these positions the major axis of such a pseudo-ellipse very often lies parallel with the limb.

Naturally, the direction of vision toward points on the arcs of the solar latitude circles influences the perspective under which the maculae are observable. The form of a parallelogram is not uncommon, or sometimes a three-sided figure can be seen—never truly geometric, but rather amorphous, or bulbous, and undergoing continual change. The formless outline of the umbra of a great macula may often be observed, when suitably magnified, to resemble the shore of an island, with inlets, bays, fjords, and smaller indentations, but lacking more than indefinite stability.

The larger maculae have an *apparently* black umbra, sometimes with a nucleus of varying area and depth of shade, its coloration at times perhaps due to optical imperfection, enclosed within a penumbra of much lesser density, but of the same general contour as a rule, and usually very plainly bounded, as in the case of Saturn's rings. Incidentally, a large isolated, well-rounded macula, when not too far from the limb, is not unlike Saturn in appearance (except that nothing shows below the penumbral ring); the similitude pertaining also to the "phases," with

their rapid changes as effected by foreshortening. A good example of such a spot was that seen August 22, 1946.

With more or less uniformity of breadth, the penumbral border or fringe is also quite variable, occasionally one-sided, and whilst it is commonly of a very light hue—a sort of ashen-gray (according to Abbot a "half-tone")[3]—as compared with the umbra, there are slight fluctuations of tint whose explanation may be difficult to seek. As to the darkness of the umbra, its reproduction in a drawing requiring a deep black carbon pencil, this must be understood to be largely an effect of contrast with the excessive brightness of the photosphere and the still greater brilliancy of any neighboring faculae, however impossible to realize the difference visually.

A penumbra is often seen surrounding a number of umbrae, and while its outline is generally sharply defined, not infrequently there is an indefinite, shadowy merging of part of the penumbra with the photosphere. Under the finest definition the penumbrae are of a thatch-like appearance, or that of filaments, in the case of the larger maculae, and one is reminded of the willow-leaf portrayal of Nasmyth fame.[4] With smaller telescopes than that used by Langley in his beautiful delineation of a "typical sun-spot"[5] it is possible to imagine something of the wealth of complicated detail which he saw through the smoky atmosphere of Pittsburgh—an ideal screen, as provided also by a homogeneous fog. The latter happens, however, but seldom, and being of precarious tenure necessitates caution to protect the eyes even with the aid of the Herschel helioscope. (In handling the decidedly practical Brashear model of this device—constructed with a wheel containing three cells for shade glasses interposed between prism and eyepiece—I used two "London Smoke" neutral screens of differing absorption, their surfaces optically true, leaving the remaining space vacant in order to take advantage of translucent fog or of uniformly thin, tenuous cloudiness. Arranged in this manner, eyepieces fitted with dark caps, or with a sliding wedge, may also be used, augmenting the utility of this invaluable accessory; another expedient thus afforded being the combination of two colors or degrees of absorption of the shade glasses—mentioned by Webb.)[6]

Groups of umbrae usually occur encompassed by a penumbra similar in general to their composite structure, and when a single umbra breaks up the penumbra seems to be inelastic enough to resist more than concordance with the whole as a mass phenomenon. Sometimes the matter of the photosphere comes between adjacent penumbrae, and one of its phenomena is that of bridging over or dividing a macula. This arching is distinct from the common appearance of discrete umbrae seeming to float in an ocean of penumbra. The relation of the units of a large group to each other often remains "in status quo" from one day to another, with little more than the partial changes from time to time ascribable to these magnetic storm centers, which include their coalescing as well

as disintegration during the growth and subsequent diminution of activity through the life of a disturbance.

It must be borne in mind that we are endeavoring to analyze and describe phenomena almost a hundred million miles away, and while our optical means can readily contract this interval to the equivalent of a million, or, say, half a million miles, or as little as the distance of the Moon (a quarter the Sun's diameter), a great group of maculae is still too far from the eye to discern all that it constitutes. In the absence of ample magnifying power it is only with the ingress of a group within easy naked-eye visibility that we can get practically near enough to the source to sense something of its wondrous meaning. These are so few as to become historic, and recourse must be had to other than direct visual examination of the Sun's luminous shell (relatively no thicker than the rind of an orange) to glean further information of the nature of the maculae and faculae when out of reach of ordinary telescopic scrutiny.

How often the writer has been impressed with the superb magnificence of a group of maculae and contiguous faculae as they come into view over the Sun's eastern limb! (As in the morning of September 13, 1946.) Even at that depth in the solar atmosphere, what a glorious scene is presented when such a grand arena of activity enters the ken of the telescope! And when one grasps something of the colossal spread of such a group as that which again appeared over the edge of the disk on July 20, 1946—not less than two and a half billions of square miles—it enables a better idea of the immensity of the Sun's distance and diameter, although without being more than an aid toward true comprehension. But the square mile unit, when used in dealing with group areas, is utterly inadequate to convey any conception of their absolute extent, just as the unit of a mile fails in stellar distances.

In the matter of size the maculae alternate between great gaps that could engulf one of the outer planets—possibly Jupiter itself—to smaller openings through which any or all of the inner planets could be lost; and in decreasing scale to the minute black dots and pores (oftentimes at the extreme limit of vision), whose area dwindles to insignificance. Some of these are the merest points of black which are manifest only when the seeing is at its best. (Latterly, I have found the Willson yellow filters an improvement over others in defining these smallest of spots.) Curiously enough, it often happens that they appear within the penumbra of a large macula, frequently at its outer edge, and sometimes in swarms or short streams. As comparison, such a macula may cover hundreds of millions of square miles, while the tiny ones may not exceed some tens of thousands, but at that as big as one of the lesser states of the Union. It would seem that the "dwarfs" and the "giants" are represented in sun-spots as well as among the stars.

As my drawings are made to a scale of eight inches to the Sun's

diameter of 864,000 miles, of which one-eighth of an inch equals 13,500 miles at the center, therefore its square 182,250,000 miles, it is a very simple thing to estimate the area of a macula group—at least essentially correct measurement with its progressive positions from day to day—making allowance for the curvature of the solar globe.

The miniature spots spoken of as satellites of the larger maculae often occur independently in groups or clusters of diverse arrangement and with much variety of diminutive size. Possibly some arise from regions wherein they are preceded by the intangible veiled spots of Trouvelot;[7] their duration affected by nether-photospheric action, comparable it may be to that which causes the terrestrial phenomena of geysers. They are transient and their visibility is mostly dependent upon clarity of seeing—momentarily in and out of sight as one gazes intently, with unstable definition. And one must always be on guard against optical illusion! Relevant to all this is the singular submergence and reappearance of solitary spots—not necessarily identical unless they possess individuality, which is doubtful—in any one place. These might be classified as island spots, their inexplicable behavior one of the mysteries of solar physics,—when not attributable to deficient seeing.

The spring of 1939 witnessed many splendid macula groups; thus, on May 30 of that year, as seen at 8:30 A.M., with powers of 50 and 85 —the definition exquisite—my sketch shows an extensive group containing more than sixty spots and having an area of four and a half billion square miles. The exhibition of July 8-12, 1939, was especially striking, consisting of three gigantic groups, separated by spaces of some 50,000 or 75,000 miles, and containing in all eighty spots, their combined area possibly seven billion square miles,—about six-tenths of one per cent of the hemispherical area.

The macula groups vary greatly in consistence as well as area; thus, my drawing for October 13, 1939, shows a group of one large and six small maculae, its area approximately a billion square miles, and also a complex cluster containing thirty-two small spots having an area of more than twice that much. In the first instance the spots were well separated; in the second closely packed together. On October 19, 1939, the leading spots of a large group appeared at the eastern limb, increasing in apparent extent and in the size of the principal one of the group, as it came more fully into view; their number on October 22 being twenty-three, with an area of about two billion square miles, exclusive of accompanying faculae. A group which evidenced remarkable development with the solar rotation showed up on January 6, 1940, a massive spot at each end of its trail, with a total of fifty spots, their entire area similar to that of the group of October 22, 1939. On the following morning—January 7—with the seeing very poor, only fifteen spots could be detected. This is cited because of the bearing of definition on spot counting, with its resultant uncertainty.

The ultimate of size seems to have been the macula observed in 1858, whose breadth was over 143,000 miles (presumably inclusive of penumbra) and mentioned by Young as covering about one thirty-sixth of the whole surface of the Sun, *i.e.*, of the disk.[8] On the 8-inch scale referred to, such a breadth would equal about 1⅓ inches.

As viewed in comparable positions, of one-fourth to one-third the distance from the eastern and western limbs, respectively, the vast group seen early in the mornings of October 2 and 6, 1937, its area roughly measuring five billion square miles, showed changes due to incessant activity—a very maelstrom of cyclonic energy. The number of spots counted on the first date was not less than fifty-two, of sizes from the least up to diameters of about five thousand miles; on the second date there were some fifty-five spots in the group (their sizes not greatly different from those on the 2nd), but with considerable development in arrangement and general form. On both occasions the definition was good, the power used being 50; doubtless the spot count would have increased with higher magnifying, although I have not always found this to be the case. While such groups of maculae are by no means unique, they are scarce enough to demand the most assiduous observation, particularly as their composition varies greatly.

As happened in the middle of February, 1938, maculae groups sometimes follow each other so closely in a stream as to suggest similarity of connection in the cause that exists beneath the photosphere; sometimes for this reason it is a matter of no little difficulty to distinguish any separation between the component groups. One such elongated group, observed February 15 of that year, spread out over more than a quarter of the Sun's disk, or a distance of about 250,000 miles. On June 16, 1937, a stream of two groups, not widely separated, had a total length of 270,000 miles and an average breadth of a tenth that much—therefore an approximate area of seven billion square miles. In both groups could be counted forty-eight spots with a power of 50. Then, during maximum, a lengthy massing of groups may stretch over more than half the diameter of the disk (nearly a quarter of the Sun's circumference), as on February 15, 1938, also in September of the same year.

While watching a group in its apparent passage across the disk, when clearly seen for about ten or twelve consecutive days, one may observe many mutations in the form and size of the constituent spots where there is a good deal of activity (and it is never absent), although they may retain something of general uniformity of relationship within a shorter period. When a stream of large groups is visible at one time, it is worth while to notice the varying degrees of activity evinced by their members; but here, again, one may note at times general similarity throughout a family of groups in a spot zone. However, what seems like a minimum of motion to the eye at the telescope, while gazing for

an hour or two, is in reality seething turbulence on a stupendous scale as gauged by the known dimensions of a group whose length may be a tenth of the Sun's diameter. More pronounced in the order of evolution, and of engrossing interest, is the cumulative diversity in the aspect of a group as seen near the same limb from one rotation to the next, or during several successive rotations, until the photosphere claims sovereignty over its vicissitudes and suppresses the entire disturbance.

The width of the penumbra is not always proportionate to the size of the umbra, but as a rule there is no great dissimilarity in this respect as between the same kinds of maculae, rated by dimensions. Many of the smaller umbrae have narrower penumbral borders than their larger fellows, although without commensurate difference where there is but slight disparity in size. However, the still smaller maculae show curtailed penumbrae, sometimes not easily discerned, and often seemingly wanting; while the members of some of the groups have the appearance of being connected by penumbral substance, if it may be so designated. Thus, a comparatively few spots may seem to float in a huge sea of such matter, and often dissociated masses of penumbrae appear to unite spots of uncertain definiteness, even with fine seeing.

Some of the lesser spots alter but little as they seem to circumnavigate the Sun with the axial rotation; when large enough to show a sensible penumbra they vary slowly, through the gamut of oblique presentation, from an expanded ellipse (edgewise when next the limb) to a quasi-circle, and back again at the opposite limb, in obedience to geometric principles. They often lack more than subordinate activity temporarily, and afterward either shrink or enlarge as the case may be. Including any changes of place due to mobility en masse, the spot proper motions are difficult to follow, with the spots themselves having no such fixity as marks the lunar features; yet of a permanence that serves in determining rotation periods within well-known limitations.

Exceptional to this was a rotary motion, or "violent whirling," witnessed by Dawes in January, 1852, and illustrated in a small book on the Sun by the Rev. Robert Walker (London, 1860)—the peculiar form of the spot (with a protruding tongue or ansa) making the observation feasible over a period of several days. A recent example of proper motion easily observed was that of the little spot which accompanied a fairly large macula that came into view near the eastern limb on September 28, 1946. When first noticed, on October 1, the attendant spot was within the penumbra; at the rim on October 4; well outside the rim on October 6. The total proper motion (all eastward) was estimated as three or four thousand miles, and seemed to be the result of repulsion by the main spot. The outlier was not visible twenty-four hours later, on the morning of October 7, with near approach to the western limb, —and left not a vestige of its existence.

It goes without saying that in recording the number of spots at any

particular time, and in the study of their physical characteristics, much depends upon the state of the seeing, already alluded to, which differs so widely that when it can be classed as excellent (which is none too often) there is little trouble in sketching the groups accurately; whereas contrary conditions render it necessary to proceed with greater care. The finer the seeing the more the nicety of detail observable, especially the excessively faint spots referred to above. It is seldom that the best seeing lasts long, and the writer has found that the early morning favors satisfactory observation, the heating up of the air with higher solar altitude conducing to faulty definition. Steady work involves continual battling with the elements, making it impossible to maintain thorough efficiency in registering the appearance of the Sun.

For these and other reasons telescopes of such moderate apertures as 4 and 4½ inches are to be preferred to those of larger size, especially since the increased magnification arising from greater focal length, as in applying high-power eyepieces, may not yield details in the same ratio. Then, too, there is the additional advantage that the smaller instruments show the entire disk of the Sun with a power of about 75 diameters, or, with certain eyepieces, up to 100. (Flatness of field is important, delicate features being easily missed when slightly out of focus.) A larger aperture may be "stopped down," to reduce the superabundant light, and suitable magnifying power employed in order to command the same effect; but when the smaller object glasses are of superior quality, as with my Brashear 4-inch, there is nothing to criticize adversely in the matter of defining capacity as one becomes accustomed to such lenses. It is a case where familiarity does *not* breed contempt, with experience alone sufficing for guidance.

The life of the maculae varies within wide limits, affected by their size and doubtless as well by the degree of activity of their underlying causation. It is fascinating to watch a spot big enough to drop the Earth into, as seen from day to day, in its guise of transiting the Sun, and to remark its more or less rapid transitions with inevitable effacement impending; or the obliteration of spots of a few thousand miles breadth, as it were over night. The minor spots may not outlast the day in which they are born, and a cluster of such spots, after disappearing over the western limb, may be looked for in vain to reappear with the axial rotation. The phenomena may be accounted for as the absorption or extinction of the spots within the endless "waste" of the photosphere; at least it seems so as one witnesses a group of these inconspicuous maculae emerge where twenty-four hours earlier, or less, only the granular photospheric surface was visible, and within a like period vanish apparently beneath that level, which then looks as if not to have suffered any disturbance from below or above. Yet occasionally, as on September 4, 1946, one may suspect the passing existence of what might be called solar "flotsam and jetsam" as it sinks out of sight. Or,

on the other hand, a group of this kind may attain rapid growth, as in the case of one seen toward the end of August, 1946; they "wax and wane" in response to unknown laws of development, presumably amenable to forces at work intermittently within the sub-photospheric domain.

Comparison of my drawings with illustrations given in Dr. William Brunner's "Sun-spot Classification"[9] shows general accordance therewith, but that no two representations of each class are alike except in a typical way. The variations, indeed, are manifold, bearing out the statement in the opening paragraph of the present paper; there are no exact replicas in sun-spot manifestation,—assuredly a fact of importance.

One is led to regard the photosphere as having the character of a semi-fluid, viscous, super-heated envelope or layer varying in composition with depth, and disclosing, through the spot cavities or vortices as investigated visually, something of the upper deeps of the interior—otherwise forever hidden from optic perception. This impression is accentuated by a mammoth macula or group, particularly the latter when the umbrae and penumbrae are in a state of commotion, or even comparatively quiescent, as seen from day to day.

As to the origin of the phenomena under consideration, it would seem that the internal condition of the Sun, with its tremendous pressure and inconceivable temperatures, along with its swift and unequal rotational motion, could account for the known consequences, and that no such external influences as planetary attraction or the impact of meteorites could possibly be competent to produce the results with which we are acquainted, for there must normally be affinity between cause and effect.

The nucleus of a spot umbra is not readily observable without some special means of regulating the extent of the field of view, as with the "limiting apertures" of the Dawes eyepiece, or some other way of relieving the eye by subduing the intense black-and-white contrast between umbra and photosphere. An iris diaphragm helps to this end, and I sometimes use a "home-made" simplified form of the Dawes contrivance, consisting of a wheel containing apertures ranging from 3/16 to 1/100 inch, mounted at the focus of a high power single lens. On one occasion I could see a deep violet tinge within the umbra of a large spot, but do not recall observing the opposite end of the spectrum—red.

The faculae have the appearance of tongues and jets of super-brilliance, branching out into an intricate, chaotic network in which the macula groups often seem to be immersed. They are generally interspersed with unsymmetrical blotches of radiance against the *inferior* brilliancy of the photosphere, enhancing the contrast with the actual *light* of the macula umbrae. Whether the faculae precede or follow the maculae has been a subject of discussion, and the answer probably is that either or both are concomitants of their existence. Often announcing the advent of macula groups, their role of precursor is as likely to assume that of aftermath, but with many years of observation I cannot

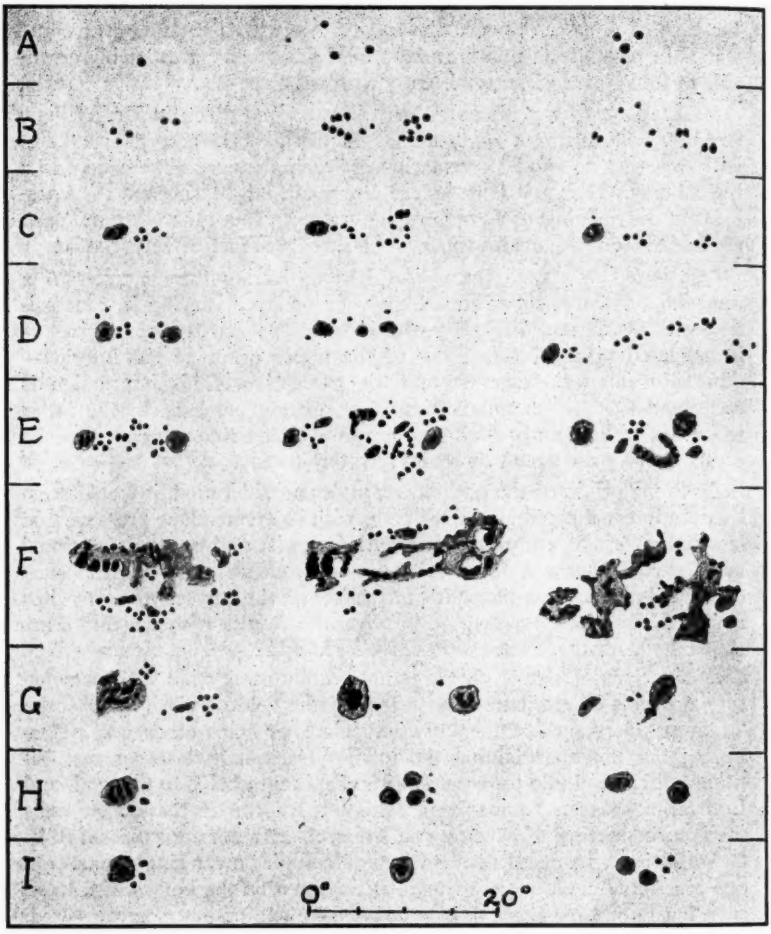

FIGURE 2

SUN-SPOT CLASSIFICATION BY DR. WILLIAM BRUNNER

A. Small single spot or small groups of small spots.

B. Stronger groups of small spots without penumbral area and groups of small spots in bipolar arrangement.

C. A small or average spot with penumbral area and small spots with penumbra and attending spots in bipolar arrangement.

D. Bipolar groups with two or three spots with penumbral area and several small attending spots.

E. Strong groups of several spots having penumbral area and many small spots.

F. Very strong groups with large irregular penumbral areas with spots in them

and many attending spots.

G. The first breaking up of the large groups. Two large spots with penumbral areas, in bipolar arrangement and eventual small ones, a few penumbral wisps between the spots. A large spot with penumbral area and smaller spots in a bipolar arrangement.

H. Medium or large spots with penumbral area showing disintegration, small spots in a closer formation or a narrow group of small or medium spots in a penumbral area which originated because of the separation of larger spots.

I. Small regular spots with penumbra or small spots within a penumbral area breaking up.

find that the connection is other than fortuitous. At all events, one may frequently notice faculae and maculae together at either limb, where from the nature of things they are best visible, although to be found throughout the spot belts, as revealed by the spectroheliograph. Observed telescopically, the faculae are not ordinarily as prominent at any great distance from the limbs, becoming gradually indistinguishable with isolation therefrom, but there are exceptional instances where faculae are unmistakable around maculae groups nearly a quarter of the Sun's diameter from the limb. At times, when near either limb, a macula is accompanied by a ring or aureola of facula—its brilliance exaggerated by the darkness of the penumbra.

When definition is above par, very faint faculae are barely perceptible here and there along the limb—not contrasting markedly with the light of the photosphere. It requires keen sight to differentiate the nuances of facula brilliance. Not to be overlooked is the occasional enormous extent of sheets of faculae, in great billows like a "mackerel sky," that may surround a small macula—their areas as a thousand to one.

If we could look upon the Sun from such a vantage point as the planet Mercury (thus gaining corresponding enlargement of the telescopic image), and if it were possible at that interval to be also in line with its north pole, we should be able to see a procession of spots around the lower part of the northern hemisphere, in the form of a ring, more or less continuous at maximum of the cycle, and of foreshortened perspective accordant with proximity to the equator. Only in this way could be learned the total life history of many evanescent groups that do not survive through a complete axial rotation, as well as of those that disappear without coming to a second apparition at the eastern limb. From our own situation in the Solar System, even with groups that come into view with successive rotations, we cannot know what takes place on the unseen hemisphere except by analogy, *e.g.*, a supposition that no great changes have occurred when there is substantial similiarity of aspect from one rotation to another. And it follows that spot apparitions take place on the unseen side, of which nothing can be known when they are dispersed without crossing the eastern limb.

The amount of photospheric light stopped by the maculae is of course a measure of the solar variability, but is at most a relatively small

quantity, ranging from zero to approximately 0.1% or rather more at maximum of the cycle, based on the hemispherical area of over 1,172 billions of square miles; using which figure a single macula of 10,000

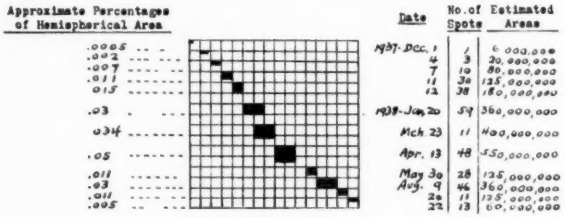

FIGURE 3

TOTAL AREAS OF SPOTTEDNESS ON SELECTED DATES
(A Square of 1/16-inch is Equal to 182,250,000 Square Miles.)

miles diameter (100 million square miles) would not hide as much as a hundredth of one per cent of the Sun's light, and less than ten times that amount might be taken to represent the limit of light intercepted by all the aggregations of maculae at the average height of maximum. Young says that the total area covered by spots never exceeds 1/500 of the whole surface of the Sun.[10] (The extraordinary spot of 1858 prevented probably less than 2% of the Sun's light from reaching the Earth.) An experimental way of determining this would be to plot all the umbrae seen at any one time into a single connected mass, adding enough to indicate empirically the penumbral shading on an equivalent scale. An appropriate number of representative days through various periods of the cycle would then give a comparison similar to that obtained by a series of observations of a variable star—ample at least to fix the stages of variability.

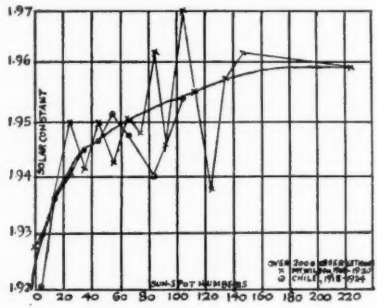

FIGURE 4

VARIATIONS OF SOLAR RADIATION
ASSOCIATED WITH SUN-SPOTS

The curve shows that on the whole higher intensities of solar radiation accompany increased solar activity as shown in sun-spots.

However slight this decrease in the brilliancy of the photosphere, with its negligible effect on the Sun's magnitude of —26.7, it must thereby be regarded as an irregularly variable star having a period of eleven years ±. Whether any star of similar absolute magnitude, as affected by cycles of spots, could be recognized as such is open to question, but if so the captivating thought arises that many other suns have in all probability the same phenomena actuating such minute differences in magnitude, though hardly determinable by direct observation. (Proctor wrote that "The spectrum of stars of the third type resembles in a remarkable degree the spectrum of a solar spot, a circumstance that led Secchi to regard these as spot-covered suns.")[11]

Solar radiation is attended with numerous variations caused by the source of spot activity, an increase in which is accompanied by greater

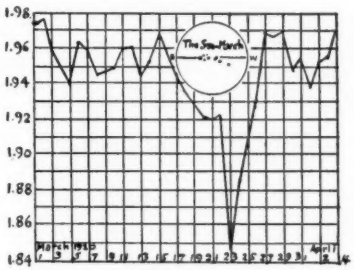

FIGURE 5
CENTRAL SUN-SPOTS DIMINISH SOLAR RADIATION

Note the large variation of solar radiation which attended the great sun-spot group of March, 1920. The minimum was observed just after the sun-spot group became central to our view, as it was carried along by the solar rotation. This sort of phenomenon (though seldom so strongly marked) almost invariably attends the passage of a sun-spot across the sun's disk.

intensity in the former. The average value assigned to solar radiation is a "constant" of 1.94 calories per square centimeter (about ⅜ inch) per minute, just outside the Earth's atmosphere, indicating a temperature approaching 6,000° Absolute Centigrade. The effect of spot activity is shown in the graph (Fig. 4) taken by permission from Abbot's "The Earth and the Stars"; while the effect of central sun-spots in the diminution of solar radiation is illustrated in another graph (Fig. 5) from the same authority also reproduced herein. The descriptive titles of the originals are given as well.

The foregoing is an attempt to narrate, within essential restrictions, some of the impressions acquired from several thousands of visual observations of the Sun, as supplemented by reading a number of the works of leading authorities on the subject. Purposely omitted are remarks upon such cognate questions as the rotational acceleration toward the equator, spot polarity, effects upon the Earth's magnetism, the lati-

tudinal limits of sun-spots, the duration of the cycles, along with auroral phenomena, the influence of spot apparitions on radio transmission, and, it may be, terrestrial weather. All these have been dealt with competently by others.

In confining my attention therefore to the title itself (suggested by Chairman Heines of the Solar Division, American Association of Variable Star Observers), I would say that no pretension is made toward completeness—which would call for much additional space—the intention being solely to cover briefly what appeals to the writer as outstanding phenomena open to the contemplation of all who care to spend the needful time at the telescope. Any who do so must agree that there is no "last word" regarding the refulgent orb which governs our material destiny.

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TREDYFFRIN OBSERVATORY, BERWYN, PENNSYLVANIA.

The Total Solar Eclipse of May 20, 1947

By LEWIS J. BOSS

Records of the early total solar eclipses in this series seem to be lacking. From the first total eclipse of the series on May 3, 1334, until April 16, 1893, no scientific observations upon any of the thirty repetitions appears to have been made. This is probably due to the fact that the path of totality in these cases lay largely over the ocean and across wild and uninhabited lands.

At the April 16, 1893, eclipse, the first return at which any serious recorded data seems to have been taken, photographs and observations were obtained by members from the Lick Observatory in Chile with apparatus which surpassed, in power and definition, any that had heretofore been used. This eclipse, which was visible throughout South America, a large part of Africa, the western part of Asia and the southern part of Europe, had its corona photographed for the first time

with a camera of forty foot focal length. This was the famous "Schaeberle mounting," erection details on which may be found in *Contributions from the Lick Observatory,* No. 4.

Also, at this eclipse, a new instrument, called a prismatic camera, designed by Lockyer and having a focal length of 7 feet 6 inches with a 45° prism, was employed. This was operated by Fowler who obtained photographs with a dispersion of 2 inches between the F and K lines. Later, 164 chromospheric lines were measured between the F and K lines on these negatives. Probably one of the most important results of the observing of this eclipse was that for the first time it was possible to separate the chromospheric spectrum from that of the corona. From this time on, it was no longer assumed that a spectral line which was visible during totality necessarily belonged to the corona.

The return of this eclipse on April 8, 1911, seems not to have been widely observed but the next eclipse in the series, that of May 8-9, 1929, attracted considerable attention and was observed by a great number of eclipse expeditions sponsored by various institutions from all over the world. A large variety of investigations into the coronal phenomena were undertaken with considerable success and motion pictures of the entire eclipse were taken.

On May 20, 1947, the thirty-fourth return in this series of total eclipses will occur. Totality will be observed within a path approximately 120 miles wide, beginning in the Pacific Ocean, just west of Santiago on the coast of Chile, thence northeasterly across South America to Bahia, Brazil, sweeping across the South Atlantic to the Gold Coast of Africa and then swinging down over the northern Congo, ending at sunset in southern Kenya. The greatest duration of totality will occur near the west coast of Africa where the sun's disc will be eclipsed for 5 minutes and 14 seconds.

Herewith are given the dates of the beginning and ending of the partial eclipses, the date of the first central (and total) eclipse, date of the middle eclipse of the series, date of the last total eclipse and date when the series ends.

1. The first partial eclipse of this series took place on December 13, 1117. All eclipses of this series take place at the moon's ascending node. (☊)

2. The first central, and total, eclipse of the series occurred on May 3, 1334.

3. The middle eclipse of the series took place on June 7, 1731. Although the middle eclipse of the series has been passed the time of totality is still increasing slowly.

4. The last central eclipse will occur on August 26, 2109, and will be total but the duration of totality will be short.

5. The series will entirely run out on February 16, 2398, with a

very small partial eclipse. The moon will just graze the edge of the sun's disc.

[4] WARWICK NECK, RHODE ISLAND, DECEMBER 26, 1946.

The Planets in June, 1947

By LELAND E. CUNNINGHAM

NOTE: The time employed is Central Standard Time unless otherwise indicated. The phenomena have been chosen and described for the North American continent, and especially for the United States. The basic data have been taken principally from the *American Ephemeris and Nautical Almanac.*

Sun. The sun will be nearly stationary in declination throughout June. It will reach its northernmost point at the beginning of summer, which occurs June 22, at 12:19 A.M., C.S.T.

Moon. The phases of the moon will occur as follows:

		C.S.T.
Full Moon	June 3	1 P.M.
Last Quarter	11	5 P.M.
New Moon	18	3 P.M.
First Quarter	25	6 A.M.

There will be a very small partial eclipse of the moon on June 3, but it will not be visible in the Western Hemisphere.

Mercury. Mercury will be unusually well placed for observation throughout June. At greatest elongation east on June 17 it will be nearly 25 degrees from the sun, and its declination will be nearly that of the sun. It will reach a stationary point on the last day of the month.

Venus. Venus will continue to be a brilliant morning star, although by the end of the month it will be only 20 degrees from the sun. An occultation by the moon on June 17 will be visible only in high northern latitudes.

Mars. Mars will be an inconspicuous morning star moving eastward in Aries and Taurus. An occultation by the moon on June 16 will be visible only in the southern hemisphere.

Jupiter. Jupiter will be visible throughout the evening hours, but it will be too far south for the best telescopic observation; it will be retrograding in Libra. The sixth and seventh of the series of monthly occultations by the moon will occur on June 1 and June 28, respectively. The emersion from occultation on the evening of June 1 will be visible from the west coast, but the occultation of June 28 will not be visible in the Western Hemisphere.

Saturn. Saturn will be an evening star low in the west.

Uranus. Uranus will be in conjunction with the sun on June 13.

Neptune. Neptune will be stationary in Virgo; it will be in quadrature with the sun on June 30.

Students' Observatory, University of California, Berkeley, April 19, 1947.

Occultation Predictions for June, 1947

The quantities in the columns *a* and *b* are given for the purpose of making these predictions useful for any place within 200 miles of the point indicated. The procedure is as follows: Subtract the longitude of the point given from the longitude of the place in question; multiply the result in degrees, taking the signs into account, by the quantity under *a* for the star to be observed; similarly, with the latitude, using *b*; apply the sum of the products, with its proper sign, to the Greenwich C.T., and obtain the predicted Greenwich Civil Time for the phenomenon at the place of observation. To obtain Eastern Standard Time it is necessary to subtract five hours; Central Standard Time, six hours, etc.

(Taken from the *American Ephemeris*)

			IMMERSION				EMERSION			
Date 1947	Star	Mag.	Greenwich C.T.	*a*	*b*	Angle E from N	Greenwich C.T.	*a*	*b*	Angle E from N
			h m	m	m	°	h m	m	m	°
Occultations Visible in Longitude +72° 30′, Latitude +42° 30′										
June 26	72 Virg	6.1	22 55.9	—1.6	—0.3	116	0 14.8	—1.3	—1.4	319
30	10 G.Scor	5.9	1 31.7	—2.5	+0.7	79	2 41.3	—1.3	—1.6	333
Occultations Visible in Longitude +91° 0′, Latitude +40° 0′										
June 29	26 Libr	6.3	5 31.9	—1.6	—1.5	109	6 49.6	—1.0	—1.8	293
30	10 G.Scor	5.9	0 56.2	—1.1	+0.3	116	2 17.2	—1.5	—0.3	302
Occultations Visible in Longitude +120° 0′, Latitude +36° 0′										
June 12	30 Pisc	4.7	11 39.0	—1.9	+0.9	102	12 34.2	—0.6	+2.9	189
23	42 Leon	6.1	5 16.3	—0.2	—1.6	118	6 11.3	+0.1	—1.5	297
29	Jupiter	—1.9	.. ..	..	..	..	0 9.4	—0.2	—0.1	309
29	26 Libr	6.3	4 45.8	—1.5	—1.5	144	6 8.1	—2.3	—0.8	277
Occultations Visible in Longitude +98° 0′, Latitude +30° 0′*										
June 28	Jupiter		23 14.9	—0.9	+0.6	102	0 22.0	—0.6	—1.0	325
29	26 Libr	6.3	5 36.4	—1.9	—1.9	128	6 57.0	—1.3	—1.3	276
30	10 G.Scor	5.9	0 56.1	—0.1	—1.5	157	2 0.9	—2.6	+1.0	265

*Computed by Edgar W. Woolard and Paul Herget; communicated by Commodore J. F. Hellweg, Superintendent U. S. Naval Observatory.

METEORS AND METEORITES

Meteor Notes from the American Meteor Society

By CHARLES P. OLIVIER, President

Continuing the tabulation of results begun in the December, 1946, Notes, the following table gives data from stations in Ohio and other states alphabetically higher. At the end are added a few which arrived too late to be included in the expected places. There only now remain the official Army and Navy reports, which I hope to give in condensed form in the next Notes. When all the data have been published, an attempt will be made to discuss the meteor stream itself in view of these observations. The more these latter are examined, the clearer it becomes that, when allowance is made for the losses due to the full Moon, the Draconid

shower of 1946 October 9 was an extremely brilliant and important one. Also no other was ever so fully observed.

As to other matters, Flower Observatory Reprint No. 67, containing Meteor Notes for 1946, has been mailed to members who paid their 1947 dues and others who have been specially active. We wish that the delinquent members would send in their dues without making me take time to send bills. Thanks to Mr. Paul S. Watson of Baltimore we were able to enclose copies of "Graphic Time Table of the Heavens," published by the Maryland Academy of Sciences, with which he is officially connected.

The writer has submitted to the American Philosophical Society the manuscript of the second paper "Long Enduring Meteor Trains," which is a continuation and revision of Flower Observatory Reprint No. 60. It is hoped that this will appear by the end of the year. The work, necessary for its preparation, has been considerable and has prevented attention being placed upon more routine A.M.S. matters for some time past.

Attention should be called again to the very extensive work in meteoric astronomy which is appearing in Russian publications. As many of the men participating there are trained astronomers, using good equipment, and as there apparently is great enthusiasm among assisting amateurs, similar groups in other countries will have to work hard to make their work equally valuable. While there is a great deal done by the A.M.S. each year, there are few members who plan their work so that a regular program is followed, or who observe enough to become really skilled. We should develop some men of really great ability.

Station and Observer	Direction	Began	Ended	Max.	Min.	Met.	Fac.	Rate Unc. Obs.	
Ohio									
Bowling Green									
Ohlemacher, R. N.		7:30	8:30		60	23	0.2	23D	1
" "		9:15	9:45		30	57		114	1
" "		11:00	11:30		30	85	0.1	170	1
Bennett, C. H.	Z	7:32	10:48		154	417	0.2		1
Bowling Green Univ. Gp.		7:32				508			17
Bowling Green Univ. Gp.		10:05	10:15		10	327			22
Dietesfeld, D.		11:00	11:25		25	905			3
Bucyrus									
Wills, Miss U.	NW	9:50	10:45		55	200	0.2	219	1
Cincinnati EST									
Houston, W. S.	NW	10:45	12:00	10:58	75	3003	0.4	(4992)	1
" "		12:00	12:15		15	178		tel.	1
" "		12:30	13:00		30	0		0	1
Anderson, J. A.	N	9:43	10:13		30	324	0.3	648	1
Cleveland EST									
Black, J. L.	N	11:25	11:45		20	9	0.2		1
Russell, J. T.		10:	12:	10:45			0.4	(6000)	1
Morris, V.	N	8:15	10:30		135	387	0.2	286	1*
Marion									
Haldeman, Mrs. W. C.	NW	9:38	12:45	10:38	111	924	0.2	(2004)	2
Painesville									
Greenberg, D.	N	10:15	11:05		20	146	0.1	438	1
Oxford									
Hershfield, Miss		8:15	11:02	10:58	86	385	0.2	277	1
								(3120)	1
Roots, Y. K.		10:30	12:00	10:43	87	2814	0.3	1941	4
								(4800)	4

Station and Observer	Direction	Began	Ended	Max.	Min.	Met.	Fac.	Rate Unc.	Obs.
Oklahoma									
Ardmore									
Richardson, J.		7:50	9:30		100	615		369	1
Frederick CST									
McLellan, P.		7:40	9:55	9:52	78	201	0.2	155	1
" "		11:15	11:45		30	0	0.2	0	1
Norman									
Richardson, T.	N	7:20	10:00	9:55	150	1246	0.3	(1650)P	1
Richardson, Mrs. P. H.		7:20	10:00	9:55	140	825	0.3	(1140)	1
Univ. of Okla. Group	all	7:23	10:34	9:51		7728	0.3	XXP	4
								2590	1
Oklahoma City									
Davis, J. G.	NW	9:40	10:20	9:55	40	468	0.2	702	1
								(1080)	1
Tulsa									
Wiggins, Miss L.		8:30	11:30	10:08	20	171		(x)	1
Stillwater									
Stratton, R.	NW	9:45	10:15	10:±		300+		(3600)	1
Waynoka CST									
Oliphant, Miss M. C.		9:30	9:45		15	500		2000	2
Oregon									
Albany PST									
Willard, Mrs. G. W.	W	8:05	8:15		10	180	0.4	1080	1
Cottage Grove									
Walther, Mrs. L.	W	7:40	7:50		10	600	0.4	3600	1
Eugene									
McClanahan, Miss A.		6:45	8:15	7:52	90	3093	0.4	2162	1
								(4404)	1
Pruett, J. H.		7:50	7:55	7:52	5	342	0.4	(4104)	1
Pruett, Mrs. J. H.		7:50	7:55	7:52	5	272	0.4	(2364)	1
Thompson, Mrs. H.		7:45	7:50	7:48	5	317	0.4	(3804)	1
Thompson, Miss H.		7:45	7:50	7:48	5	400	0.4	(4800)	1
Portland									
Eacock, C. J.	N	7:00	7:10		10	184	0.3	1104	1
Cornwallis									
Reid, Miss N.		8:00	9:00		60	1760		1760	1
Williams, Miss J.		7:30	8:30		60	540		540	1
McCalment, Miss W. J.		9:00	10:00		60	780		780	1
Moore, Miss J.		7:00	8:00		60	2000		2000	1
O'Brian, Miss P.		6:30	7:30		60	480		480	1
Portland									
Amateur Tel. Makers and Obs.									
Curey, D.		7:02	9:45	7:48	70	1318	0.3	(2640)	1
Shoffner, L.		8:23	9:48		15	198	0.3		1
Thomas, H.	NW	8:05	9:36		30	322	0.3		1
McQueen, S. A.	NW	7:35	7:47	7:44	10	450	0.3	(1800)	1
Maher, T. P.	SW, N	7:43	9:36	7:50	45	911	0.3	(3138)	1
Malarkey, T.		7:42	9:09	7:44	40	1196	0.3	(4284)	1
Smale, N. C.	W	7:29	7:54		25	109			1
Hood River									
Childs, L.		6:50	10:20	8:00	60	587	0.2	(1962)	1
Grants Pass									
Bones, B. R.		7:40	7:50		10	200	0.2		2
" "		8:15	9:15		60	403	0.2	403	1
Silverton									
Jensen, Miss A. K.		7:15	8:15		60	2239	0.4	2239	1
" "		8:35	9:05		30	131		(6000)	1
Walla Walla									
Hulbush, Mrs. V.		6:52	8:01	8:00	13	524		(2200)	1

Station and Observer	Direction	Began	Ended	Max.	Min.	Met.	Fac.	Rate Unc.	Obs.
Oregon									
Medford									
Perkins, Dr. C. L.		6:30	7:20		50	500		600	1
Lyons									
Tengacher, J.		7:00	8:17	7:30	30	1444		(3942)	1
Portland									
Goddard, A. V.		7:25	8:20	7:48	33	700		(2630)	1
Eugene									
Koupal, D.		7:15	7:25		10	342	0.4	2052	1
Anderson, M.		7:15	7:25		10	327	0.4	1962	1
Pruett, Mrs. J. H.		6:55	7:55		35	819	0.4		1
Pruett, J. H.		7:50	10:35		20	362	0.4		1
South Carolina									
Leesville									
Smith, O. T.	NW	10:50	11:10		20	136	0.1		1
South Dakota									
Dell Rapids CST									
Anon.		9:15	9:45		30	389		778	1
Sioux Falls									
Arlton, S.	NE	9:00	12:10		40	429	0.2		1
Duhon, W. J.	NW	8:00	10:00	9:30±	120	2036	0.3	(1531)	1
Tennessee									
Obion CST									
Morehead, Mrs. M. (Group)	NE	9:30	9:45		15	257	0.2		?
" "	NW	9:30	9:45		15	334	0.2		?
" "	SW	9:30	9:45		15	220	0.2		?
Sewanee									
Bairnwick School, Astr. Class, 7th Grade	NW	7:00	10:35			2700	0.4	xxx	3
Texas									
Brownsville									
Lehnus, E. C.	N	8:30	10:00	9:58	90	751	0.2	(1440)	5
Commerce									
O'Neil, Mrs. M.	N	8:05	10:01		26	127	0.2		2
McDonald Obs.									
Kuiper, Mrs. G. P.	NW	8:03	8:33		30	220	0.2	660	3
Morton									
Morris, E. A.	W	8:35	9:05		30	200	0.2	400	2
Washington									
Deer Harbor PST									
Laucks, Mrs. I. F.		7:40	9:00	7:52		227	0.3	(4540)	1
Kennewick PST									
Siegfried, J. H.				8:40		99		264	1
Olympia									
Bennett, W. A. G.		7:50	8:00	7:55	10	419	0.4	(2514)	1
Pasco PST									
Oberst, W.			8:	8:00±	5	280	0.3	(3360)	5
Pullman									
Bidlake, Miss M.		7:	9:	8:±			0.4	(3750)	1
" "		9:30	10:30		60	410	0.4	410	1
" "		10:30	11:30		60	285	0.4	285	1
" "		11:30	12:30		60	72	0.4	22	1
" "		12:30	13:30		60	65	0.4	65	1

Station and Observer	Direction	Began	Ended	Max.	Min.	Met.	Fac.	Rate Unc.	Obs.
Washington									
Seattle									
Norton, W.	W	7:15			1	74		(4440)	1
" "	W	7:20			1	91		(5460)	1
" "	W	7:30			1	96		(5760)	1
" "	W	7:33			1	117		(7020)	1
Rutkowski, E.	N	9:07	10:30		83	147			
Dolley, J. S.		8:05	8:29	8:±	9	142		947	1
Wisconsin									
Milwaukee CST									
Whitney, C. A.		9:34	9:44		10	102	0.1		4
" "		10:05	10:15		10	11	0.2		1
Vermont									
Burlington EST									
Green, G.	NW	11:40	12:40		60	65	0.3	65	1
Alaska									
Fairbanks 10^h W									
Johnson, M. C.		6:30			10	106		636	2
Venezuela									
Jusepin EST									
Corrales, L. E.		8:	10:					50P	1
Canada									
Arvida EST									
Gummer, W. K.		9:40	9:55		15	38	0.1	152	1
" "	N			12:±			0.4	(400)	1
Kingston									
Morrison, Miss J.	NNW	10:15	11:00	10:55	20	383	0.4	(1716)	1
Saskatoon									
Buscombe, W.	W, S	6:55	8:00		40	69	0.1		1
California									
Alameda PST									
Roemer, Miss A.		6:24	9:29	7:50	50	886	0.4	1063	2
								(3384)	2
El Cerrito PST									
Luey, Dr. F. A.		6:30	8:05	8:00	20	445		(2100)	1
Fallbrook PST									
Forsyth, E. H.	N, E, S, W	5:55	7:50	7:48	115	2107	0.4	(3216)	4
Michigan									
Big Rapids									
Peterson, Miss M.		8:30	11:05		47	209	0.1		
Corsant, Tom		9:17	10:02		45	221	0.2		1
Illinois									
Chicago CST									
Anderson, R. F.		11:15	13:55			13	0.0		1
Ships at Sea:									
Am. S.S. Button Gwinnett EST									
λ 77° 00′ W									
ϕ 25° 50′ N		10:18				showers			1
Am. S.S. Esso Annapolis CST									
λ 90° 23′ W,									
ϕ 26° 26′ N		9:00	10:30					(5400)	1
Am. S.S. Sea Hawk									
λ 103° 43′ W,									
ϕ 14° 15′ N		"during night"				vast number			

*1+.

Flower Observatory, Upper Darby, Pa., 1947 April 15.

Contributions of The Meteoritical Society

(Known Formerly as The Society for Research on Meteorites)

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A Report on Searches for Possible Lunar Meteoric Phenomena*

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ABSTRACT

If the Moon were completely devoid of an atmosphere, as the textbooks assert, meteorites would strike its surface at full cosmic velocity. Both theoretical and observational evidence shows that the impact at cosmic velocity of a relatively small meteorite with the surface of the Moon would produce a flare easily visible from the Earth. Fully 65.7 hours of attentive systematic observation of the unilluminated portion of the Moon have not certainly revealed one such meteoritic impact-flare. There have been observed, however, 10 moving luminous specks of short duration, seen projected against the Moon. An analysis of the characteristics of these luminous specks and of their paths is given in this paper. None of the results obtained in this analysis precludes the possibility that the observed luminous specks were lunar meteors; and it is shown that the number of such specks so far observed is roughly equal to the expected number of lunar meteors visible under the circumstances of the observations.

Over 50 years ago W. H. Pickering pointed out that luminous meteors must exist in any possible thin lunar atmosphere.[1] In 1921 J. W. Gordon estimated that 20,000 or more meteoritic impacts would occur daily on the unilluminated portion of the assumedly airless lunar surface and expressed surprise that neither telescopic nor naked-eye observers had reported observations of the luminous phenomena resulting from such direct impacts.[2] At the same time A. C. D. Crommelin explained the absence of observations of such flares by pointing out that even an extremely tenuous lunar atmosphere might serve as an effective shield against meteoritic bombardment.[3, 4] Pickering had reached the same conclusion.[1] In 1925 L. La Paz communicated to C. P. Olivier by letter calculations showing that on a completely atmosphereless Moon, meteorites striking the lunar surface with undiminished cosmic velocities would produce impact-flares many of which would be bright enough to be easily visible from the Earth.[5] In 1938 L. La Paz published a paper that reached this same conclusion on both observational and theoretical grounds, and estimated that on a totally atmosphereless Moon there would be produced 100 impact-flares each year, bright enough to be visible to the naked eye from the Earth, on the non-sunlit part of the Earth-turned lunar hemisphere.[5] He called attention to W. H. Pickering's explanation that, because of the Moon's feebler gravitation, any lunar atmosphere will thin out with increasing altitude far more slowly than does the Earth's atmosphere, so that there must be some height h above the surfaces of the two bodies where their atmospheres are of the same density (unless the surface density of the lunar atmosphere

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is exactly zero).[1, 5] At heights less than h, the Earth has the denser atmosphere; but at heights exceeding h, the Moon has the denser one. Pickering computed the value of h to be 53 miles.[1] Crommelin gave 43 miles.[4] La Paz, from a critical study, obtained 44 miles.[5] If one considers only the lunar gravitation, one obtains 56 miles for h, if the surface density of the lunar atmosphere is 10^{-4} times that of the terrestrial atmosphere, and 70 miles if it is as little as 10^{-5} times that of the Earth. Terrestrial meteorites are consumed at greater heights; and it follows that the Moon, for such values of h, is *better* protected from meteoritic bombardment than is its primary!

In a former paper[6] I reported on preliminary searches for possible lunar meteoric phenomena. In such searches there are 2 possibilities:

1. If the Moon has no atmosphere at all, or a thin enough atmosphere, there will be seen flashes of meteoritic impact.

2. If the Moon has a dense enough atmosphere, luminous meteors in that atmosphere will be observed. These will manifest themselves as luminous specks moving short distances across the lunar surface during their brief periods of visibility. They will be inconspicuous, for a meteor is 16.9 stellar magnitudes fainter at the average distance of the Moon than at a distance of 100 miles. Ten (10) objects of just such a nature are known to me to have been seen in 1941-46. The data follow in Table 1.

Of these 10 specks, nos. (6), (7), (9), and (10) were seen while the observer was systematically watching for possible lunar meteoric phenomena; the other 6 were remarked in the course of ordinary lunar observations. It should be emphasized that *for all 10 specks,* the observer had *complete confidence* in that he had actually observed a moving luminous speck. I feel as certain of the reality of the 7 specks that I recorded as I do of the reality of a third-magnitude terrestrial meteor observed with the naked eye under favorable conditions.

One may ask whether some terrestrial cause low in the Earth's atmosphere can explain these specks. Such an explanation appears most unlikely, for these objects were seen *bright* (not dark, like birds or insects) against the Moon, and they crossed only a small part of the telescopic field of view. Moreover, the moving specks had very definite end-points to their luminous paths. Furthermore, any suggested terrestrial cause or causes would have to have been operative over much of the year (*cf.* Table 1) and would have to have existed at the 6 different stations involved, with widely differing local conditions (New Waterford, Ohio; Le Grand, Iowa; Radford, Virginia; Upper Darby, Pennsylvania; Chloride, New Mexico; and Albuquerque, New Mexico).

Are these specks terrestrial telescopic meteors? I have seen one such object cross the whole field of view during a lunar observation, and there is at least one past record of a bright meteor that crossed part of the Moon and then was seen projected against the sky;[7] I think that such an explanation might well apply to (3) and (8), which had the longest paths, and possibly to others of the 10 specks. It is indeed quite impossible to tell whether a particular moving luminous speck seen against the Moon is in the Earth's atmosphere or in the Moon's. Nevertheless, it appears out of the question to regard all 10 objects as terrestrial meteors; their angular paths were too short. These paths were all less than 7′ 20″, and only 2 exceed 55″.

In a study of telescopic meteors in which special attention was paid to whether these objects had beginning- or end-points in the field of view, F. G.

TABLE 1

	(1)	(2)	(3)	(4)	(5)
Observer	W. H. Haas	R. G. Johnson	C. P. Smith	W. H. Haas	W. H. Haas
Date (U.T.)	July 10, 1941	Aug. 24, 1942	Feb. 20, 1943	Feb. 20, 1943	May 5, 1944
Time (U.T.)	$5^h\,44^m$	$3^h\,36^m$	$2^h\,30^m$?	$3^h\,20^m$	$4^h\,6^m$
Telescope	6-in. refl.	8-in. refl.	5-in. refr.	18-in. refr.	18-in. refr.
Geocentric α of the Moon	307°	305°	151°	152°	189°
Geocentric δ of the Moon	−15°	−17°	+12°	+12°	+1°
Age of the Moon	16^d	12^d	15^d	15^d	12^d
Observing Conditions	rather poor	fairly good	fairly good	fairly good	poor
Lunar λ of the Speck*	−38°	+44°	−10°	−8°	−54°
Lunar β of the Speck*	−18°	+47°	+11°	+51°	−48°
Lunar Direction of Motion	Eastward	Northward	Southeastward	Northward	Northwestward
Length of Path (in Miles)**	63	18	144? (94-194)	22	15
Stellar Magnitude of the Speck	8?	4?	4?	8?	7?
Angular Diameter of the Speck	<0″.5?	0″.5-1″.0?	≦1″?	≦0″.4	0″.5
Duration of the Speck	1^s.0?	0^s.25-0^s.33	0^s.75 (0^s.5-1^s.25)	0^s.5	1^s.5
Velocity (in Miles/Sec.)	63?	54-72	152? (75-388)	44	10

TABLE 1 (Contd.)

TABLE 1 (CONTD.)

	(6)	(7)	(8)	(9)	(10)
Observer	W. H. Haas	W. H. Haas	R. Schmidt	W. H. Haas	W. H. Haas
Date (U.T.)	June 27, 1944	Aug. 11, 1944	June 10, 1946	July 22, 1946	July 22, 1946
Time (U.T.)	$1^h\,52^m$	$8^h\,15^m$?	$2^h\,30^m$	10^h26^m	$10^h\,56^m$
Telescope	18-in. refr.	18-in. refr.	12-in. refl.	6-in. refl.	6-in. refl.
Geocentric α of the Moon	170°	50°	207°	36°	36°
Geocentric δ of the Moon	+9°	+13°	−7°	+10°	+11°
Age of the Moon	6^d	22^d	10^d	23^d	23^d
Observing Conditions	rather poor	poor	—	fairly good	good
Lunar λ of the Speck*	−14°?	+20°?	−23°	+20°?	−6°
Lunar β of the Speck*	−30°?	+35°?	+31°	+35°?	+15°
Lunar Direction of Motion	Northward	Westward	Northward	Northward	—
Length of Path (in Miles)**	55	25	500?	35	$\leqslant 3$
Stellar Magnitude of the Speck	9†	11	1?	8	6†
Angular Diameter of the Speck	$<0''.5$	$<0''.4$	$0''.5$?	$3''.0$?	$<1''$
Duration of the Speck	$1^s.0$?	$1^s.5$-$2^s.0$	$1^s.0$	$1^s.0$?	$3^s.0$
Velocity (in Miles/Sec.)	55?	12-17	500?	35?	$\leqslant 1$

NOTES TO TABLE 1

*For the center of the path.

**Here is given the component perpendicular to the line of sight as measured upon the Moon's surface.

†Variable and dimmer toward the end of the path.

Watson found that only 52 meteors out of 174 had both these points inside the telescopic field.[8] He used a 4-inch refractor for these studies, and the diameter of the field of view was 220′. The empirical probability that a meteor should both begin and end within the field of view was therefore 0.30. It is obvious that this probability is *far* less when the diameter of the field is constricted to 10′ or less, as is the case in most lunar observations. How likely is it that 10 out of 11 terrestrial meteors should have their luminous paths wholly within the field of view? Bernoulli's formula[9] tells us that when an event has a probability of occurrence p, the probability P that it will occur just n times in m trials, $m \geqslant n$, is given by:

$$P = p^n (1 - p)^{m-n}{}_m C_n.$$

With $p = 0.30$, $m = 11$, and $n = 10$, $P = 4.55 \times 10^{-5}$. Tho surely too large, this value of P is still so small that the hypothesis that all the specks were terrestrial meteors must be abandoned.

Let us now examine some of the consequences of the supposition that our 10 moving luminous specks were lunar meteors. The stellar magnitudes as seen from a distance of 100 miles would range, then, from —6 to —16, with much uncertainty; these values compare well enough with those for unusually brilliant terrestrial fireballs. The durations appear surprisingly short, however, for objects of such brilliance, *if* terrestrial analogy applies. Perhaps we have been able to observe only the most brilliant portions of the paths. The velocities given previously are minimum selenocentric velocities for the observed portion of each luminous path. The true selenocentric velocity could be found if it were possible —and it is not—to determine the inclination of the path to the line of sight. The cosmic velocity just outside the Moon's atmosphere would be greater than this selenocentric velocity, but by what amount is quite uncertain. The heliocentric velocity can be either more or less than the selenocentric and can differ from it by as much as 19 miles/sec. for the extreme cases that the meteorite either overtakes the Moon or meets it head-on. The heliocentric velocity cannot here be obtained from the selenocentric, because the radiant is undeterminable. The parabolic heliocentric velocity at the Moon's distance from the Sun is 26 miles/sec. The question whether meteorites sometimes possess higher, *i.e.*, hyperbolic, velocities has occasioned much controversy.[10] Most of our 10 specks appear to have had hyperbolic velocities, but *great* uncertainties in the estimated durations, and great enough uncertainties in the path-lengths, as well as lack of data needed to find the cosmic heliocentric velocities, preclude a more definite statement. Specks (5) and (9), the only ones to show clearly observable angular diameters, would have had, at the distance of the Moon, linear diameters of 0.6 and 3.4 miles, respectively. The latter figure is very uncertain; the former accords with what has sometimes been found for brilliant terrestrial fireballs,[11] such dimensions naturally not relating to the *meteorite* (*i.e.*, the mass) itself. It will be noted (Table 1) that the 10 specks were fairly randomly distributed over the Moon's surface, the lack of one in the fourth quadrant having been due presumably to the smaller amount of observing time given to lunar features there. These possible lunar meteors were apparently of constant aspect thruout their paths, except (6) and (10); all moved at a uniform rate, as nearly as could be ascertained; and not any left trails behind them, except (8) and possibly (3). Their colors were yellow or white.

We wish to discuss next systematic searches made for either lunar meteors

or lunar meteoritic impact-flares. Almost all the data at hand come from 4 sources:

1. L. La Paz with a 6-inch refractor in 1927-28.
2. L. La Paz with a 4-inch refractor in 1938.
3. E. K. White with a 9-inch reflector in 1943-46.
4. W. H. Haas with an 18-inch refractor and two 6-inch reflectors in 1941-46.

In 1934 and 1936 Miss D. Hoffleit looked for lunar meteors with a 15-inch refractor,[12] but complete data on her searches are unavailable to me.

The total amount of time spent in all of the searches by all of the observers (except Miss Hoffleit, here and later) is 65 hours, 43 minutes. The stellar magnitude of the faintest moving speck that could have been seen on the Moon was 8.9, if a weighted mean is taken according to the minutes spent in the individual searches. The corresponding stellar magnitude at a distance of 100 miles is —8.0. The method of weighting stellar magnitudes here used is surely too conservative. Possible lunar meteoric phenomena will grow very rapidly more numerous with decreasing brightness; and two 1-hour searches, one with limiting stellar magnitude 5 and the other with limiting stellar magnitude 11 together have a much better chance of revealing either lunar meteors or lunar impact-flares than a 2-hour search with limiting magnitude 8. The lunar area covered by the searches was 1,040,000 (to 4 significant figures) square miles, again when a weighted mean is used. The fruit of these searches is 4 possible lunar meteors. This indicated frequency would imply, with great uncertainty, that approximately 300 meteorites producing meteors of stellar magnitude —8 or brighter encounter the Earth (surface area, 200,000,000 square miles) in each 24-hour day, *on the assumption* that a meteorite would cause an equally bright meteor in the terrestrial and lunar atmospheres. An extrapolation of a formula for the total annual infall of meteoritic material of any given stellar magnitude at the level of an ordinary meteor,[13] and the underlying assumption that the mass of a meteorite that produces a meteor of the second magnitude is 114 milligrams, show that the Earth encounters, each year, approximately 25,000 meteorites producing meteors of magnitude —8 or brighter. The daily rate is, then, near 70, and the agreement with the foregoing figure is perhaps as good as ought to be expected. If the mass of a meteorite producing a second-magnitude meteor is taken as 40 milligrams,[10] we get a much better accordance.

Absolutely no flashes of meteoritic impact were observed in the course of the searches under discussion—unless possibly speck (10) was such. In other words, there were no flares of stellar magnitude 9 or brighter, as seen from the Earth, over a lunar area of 1,040,000 square miles in a period of 65^h7. La Paz has computed, on the basis of reports on the famous Siberian fall of 1908 June 30, that a meteorite of mass 1.76 pounds striking the surface of a completely airless Moon with a cosmic velocity of 50 km./sec. would cause a flare of stellar magnitude 3.5 as seen from the Earth.[5] It follows that for this velocity a meteorite of mass 0.011 pound = 5.0 grams would produce a flare of stellar magnitude 9. Now if we again suppose that the mass of a meteorite producing a meteor of the second magnitude in the Earth's atmosphere is 114 milligrams, it follows that a meteorite of mass 5 grams would in the terrestrial atmosphere make a meteor of stellar magnitude —2. The use of Wylie's formula[13] would then give us each year over 11,000,000 meteorites producing meteors of this luminosity or brighter that en-

counter the Earth, or about 57,000 upon the lunar area examined. We may perform this calculation in another way. Watson[10] makes a meteorite of mass 5 grams give rise to a meteor of stellar magnitude —3 (to the nearest whole magnitude), and indicates that 47,000 objects causing meteors this bright or brighter enter the Earth's atmosphere each day. This figure corresponds to 89,000 in a year upon our lunar area, a value agreeing fairly well with the other estimate. We shall be conservative, however, and consider that only 5,000 flares are to be expected in a year on the lunar region searched.

Bernoulli's theorem[9] implies that if N events are distributed at random over a period of time T, the probability $p(j)$ that a particular one of the n equal intervals into which T is divided contains exactly j events is:

$$p(j) = {}_nC_j\, p^j\, (1-p)^{n-j}, \text{ where } p = 1/n.$$

For us, $n = 133$, since 65.7 hours is 1/133 of a year, and $N = 5{,}000$. Hence, $p(0) = 4.09 \times 10^{-17}$, $p(1) = 1.55 \times 10^{-15}$, and $p(2) = 2.93 \times 10^{-14}$. These very small values appear to show clearly that *extremely few meteorites reach the surface of the Moon with undiminished cosmic velocities.* The negative observations here used were made *by observers looking attentively for phenomena that they were unable to see.*

It may be worth while to ask how many terrestrial telescopic meteors the searches should have revealed. A study reported by Öpik[14] gave 264 as the deduced *true* number of meteors of stellar magnitude 9 or brighter that passed thru a field 6°.0 in diameter in 76.2 hours. The field of view employed in our searches was not more than 15′ in diameter; hence only 0.4 terrestrial meteor was to be expected. As remarked before, we saw at least one (it being uncertain whether a few of the 10 specks also belong to this category).

One may wonder why luminous moving lunar specks have gone unrecorded in the past, if they are as common as our total of 10 implies. It is a sufficient answer to the question to point out that:

1. An observer not mindful of the possibility of lunar meteors would be likely to attach little importance to their appearance.

2. Many persons would not publicize observations of such an apparently extraordinary nature, the more so since confirmation by others at a later date would be impossible.

3. Chance observations of this kind are most likely to be made by amateurs, who are far more numerous than professionals. Few amateurs publish anything at all; and surely very few professionals, if they did hear of such records by amateurs, would see fit to publish them.

It is a pleasure to acknowledge the assistance of Dr. Lincoln La Paz in the development of the ideas presented in this paper.

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1946 August 20

Adventures in a Magnetic Search for Meteorites*

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ABSTRACT

Powerful, localized anomalies were discovered by magnetometer operations in 2 different localities, leading to an investigation of those areas as the possible sites of buried meteoritic material. Excavation of one locus resulted in the complete vanishing of the anomaly and revealed nothing of a magnetic nature, altho some of the boulders in the area displayed a slight polarity. Investigation of the other site resulted in a similar disappearance of the anomaly. It is believed that the excavation process disturbed a curious pole-to-pole arrangement of the boulders, which had formed a powerful magnetic eddy in the Earth. The question is posed as to a more satisfactory explanation of this phenomenon.

About the year 1931, Mr. Harry Aurand of Denver, Colorado, told me of a very peculiar anomaly that he had encountered while making a magnetometer survey 4 miles east of Tatum, New Mexico. He remarked on the extremely local nature of the anomaly. He had encountered it while attempting to get a reading from a location on the highway, and thought that his instrument was out of order, but, after several trials on different days, he decided to trace out the offender. He found that, by setting up stations very near together, there was a very definite closure around an exact point which he marked by a small monument. My attention was called to the case for the reason that he suspected that a buried meteorite might have been responsible for the remarkably strong magnetic high in a region where only caliche characterized the surface rocks. It was several years later, about 1937, when I secured a small fund for the purpose of investigating this phenomenon. With my son, Robert, I proceeded to the location. It had been my purpose to check the spot with a magnetometer, but, being unable to secure one, we went on Mr. Aurand's notes only. These were very specific, however, and we had no trouble in locating his marker. We surveyed the area with one of the commercial "treasure finders" that we had found to work successfully in locating buried meteorites, but we could find no evidence of any metal. The instrument had been proved effective to a depth of only some 2 feet, however; so we could hardly consider the possibility of buried meteorites eliminated, since there were several records of recoveries at depths of from 5 to 14 feet.

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*Read at the Ninth Meeting of the Society, 1946 September.

Employing a local driller of water wells, we drilled to a depth of about 38 feet on the site of the marker. Nothing out of the ordinary was encountered; so we moved about 18 inches and drilled again. All cuttings were examined carefully, and any suspected particles were tested with a magnet and also chemically for nickel, but absolutely no evidence of anything resembling either a meteorite or any other magnetic mineral was found. We left the site feeling unsatisfied but resolving that at some future time we would return for further investigation.

From 1943 to 1946 I was employed by an oil company engaged in exploration. It was in this connection that a magnetometer operator reported to me that Mr. George Riggs, another operator, had told him of a very troublesome spot that he had located in Reeves County, Texas, some 6 years before, while conducting a magnetometer survey for a major oil company. He reported an anomaly of 1200 gammas in the space of about 12 feet. Fortunately, Mr. Riggs had marked the location exactly on his map, so that we were able to reach it without difficulty. Mr. A. J. Whelan, employed by the firm of Mark Whelan of Artesia, New Mexico, was taken as magnetometer operator. He checked the locations given by Mr. Riggs and found almost exactly the same gamma differential as reported by Riggs. We, however, set up many more stations, altogether 38; 34 of these were at 5-foot intervals or less, and 4 outlying ones were placed at a distance of about 50 feet, in 4 directions, to give us the regional readings. The readings gave a very definite pattern, with a NW-SE axis, 5 feet in length, where the readings were 1450 to 1559 gammas. From this axis the reading dropped abruptly to —3 at a point 7 feet to the SW. The drop was less rapid to the NE, N, and SE, where the regional normal of about 450 was reached in a distance of about 12 feet.

We had not come prepared to do any excavating. Consequently, we dug about 2 feet with such tools as we had, finding that the formation consisted of pebbles and small boulders of malpais, some of which were cemented by caliche, interspersed with a more or less sandy clay. The whole is a Pleistocene deposit of alluvium. A careful study of the terrane showed no sign of any surface disturbance whatever; so we concluded that there must be either a magnetic boulder (an assumption that was entirely unjustified, on the basis of a study of the surface rocks) or a meteorite of pre-Pleistocene arrival. Permission was obtained from the Popham Land and Cattle Company to excavate. A month later we returned prepared to dig. We had decided to use the pick-and-shovel method, rather than power machinery, so as better to study the formation. Before beginning the excavation, the axis and certain other points were checked by the magnetometer and were found to be almost exactly the same as on our previous visit. A trench was then started in a NW-SE direction, 10 feet long and 3 feet wide. When a depth of 2 feet had been reached, the bottom was leveled off and the magnetometer was set in the bottom and read. The reading was 10 scale divisions—about 310 gammas—higher. Everybody began to get excited, for it looked like big game ahead. The digging was resumed, and there was no tendency to shun the tools; in fact, the two recently returned "G.I.'s," whom we had employed to help with the digging, fairly monopolized them! Outlying-station readings were checked and all were consistent with our first reading. When a depth of 3 feet was reached, another reading was made in the trench. This time the reading dropped 9 scale divisions below the surface reading, or 19 scale divisions below the previous one. Outside stations were again checked. All were consistent with the reading at the time of our arrival. We had arrived about 11 A.M., and the day was per-

fect, so that no diurnal change was as yet to be expected. We were thoroly puzzled, but continued the operation, altho the workers began to lose some of their enthusiasm! While the digging was proceeding, Mr. Whelan and I tested many of the removed pebbles and boulders for their effect upon the instrument. We found them very weakly magnetic and showing only slight polarity. Some few were noticeably more effective than others, but all had to be brought to within a few inches of the instrument to change its reading noticeably. When a depth of 52 inches was reached, another reading was taken in the trench and the result was even below the average for the general region. All of the anomaly had vanished! Readings at outlying stations were again taken and were found to be consistent with our first readings. Here indeed was a strange phenomenon: an anomaly that covered only about 2 square rods, but that showed a greater magnetic differential than do the most pronounced oil structures in that area, even when they cover a territory of many square miles; yet the anomaly vanished before our very eyes in the course of 3 hours!

We did more checking of the material removed from the hole and found that a group of boulders, rather larger than the normal of those that make up the deposit, had been taken from a depth of about 3 feet, where they had been embedded among pebbles of normal size. These had been rather firmly cemented by caliche, but not more so than in certain other parts of the excavation. They did, however, show slightly more influence on the instrument when brought near it, and they did show definite polarity. When all of the members of this group, some 7 or 8 in number, were piled together, directly under the instrument, they changed its reading only about 2 scale divisions, or about 62 gammas. The only magnetite found in the digging, or in the whole region, for that matter, was in the form of magnetic sand, and there was no noticeable concentration of this in any part of the excavation.

The only plausible explanation of this phenomenon that we have been able to think of is that, since the malpais boulders and pebbles have a slight polarity, they have perhaps a considerable capacity for magnetization. In the rare event that several boulders are nested together in a favorable pole-to-pole arrangement, then the Earth's magnetic field may gradually build up a powerful magnetic eddy sufficient to exert the influence that our instrument detected. When our excavation broke up the alinement, naturally the magnetic anomaly vanished. We crave a better explanation, however, from those who are more familiar with magnetism than we are!

Between the time when we first examined this anomaly and that of our return for the excavation that proved so disastrous to our meteoritical interpretation of it, we had our operator go with his instrument to the Tatum, New Mexico, location which had so puzzled Mr. Aurand and to which we had always hoped we might return, some day, for a more satisfying investigation. We were quite taken aback when the operator reported that he could find no anomaly there whatever! He had checked over a rather wide area and then had gone some distance away and had set up a station; all of the readings were entirely consistent with the normal magnetic field of the Earth! It appears that what we had done to the Reeves County, Texas, anomaly by excavating, we had done also to the Tatum, New Mexico, anomaly by drilling 3 8-inch holes! Who has the answer?

On the Origin of the Carolina Bays

In his interesting article about "Observations on the Carolina 'Craters' or 'Bays'," in the April, 1947, issue of these CONTRIBUTIONS, Mr. Brandon Barringer has adduced several additional reasons for disbelieving in the meteoritic hypothesis of the origin of the Bays. Ever since reading and reviewing the late Douglas Johnson's scholarly and exhaustive treatise on *The Origin of the Carolina Bays*,[1] some 4 years ago, I have been convinced that no genetic connection exists between those remarkable topographical features and meteorites. Regardless of whether one is prepared to accept Johnson's "artesian-solution-lacustrine-aeolian hypothesis" —or "hypothesis of complex origin," as he called it for short—as the final explanation of the formation of the Bays, one is nevertheless inclined, after a perusal of the forenamed work, to concede that, by his field studies, theoretical investigations, and thorogoing arguments, Johnson pretty effectively disposed of the meteoritic hypothesis. If so, then future research on the Bays will belong evidently, not to the realm of meteoritics, but to the sphere of geomorphology.[2]

F.C.L.

[1] Douglas Johnson, *The Origin of the Carolina Bays*, xiv + 341 pp., Columbia Univ. Press, 1942; reviewed by the undersigned in *Astroph. Jour.*, **98**, 132-3, 1943.
[2] *Cf.* the last 2 paragraphs of the review referred to in n. (1), *ante*.

Second Notice of the Tenth Meeting of the Society

As announced in the April issue, the Tenth Meeting of the Society will be held on Wednesday, June 18, and Thursday, June 19, 1947, in connection with the meeting of the Pacific Division of the American Association for the Advancement of Science in San Diego, California. The afternoon session of June 19 will be a joint session of our Society and the Astronomical Society of the Pacific. The members of the Meteoritical Society will be notified individually at a later date of the precise address and hours at which the meeting will take place. All the scientific sessions of the meeting will be open to the public, and guests as well as members are cordially invited to attend.

President King has appointed the following members to serve on the Program Committee for the Tenth Meeting: Walter H. Haas, Albuquerque, New Mexico; Frederick C. Leonard, Los Angeles, California; J. Hugh Pruett, Eugene, Oregon; and John A. Russell, Los Angeles, California (Chairman). The President and the Secretary of the Society are *ex officiis* members of the committee.*

**Addendum, April 15:* The headquarters of the meeting will be the U. S. Grant Hotel, 326 Broadway, in downtown San Diego. The morning and afternoon sessions will begin at 9 A.M. and 2 P.M., respectively.—J.A.R.

JOHN A. RUSSELL, *Chairman, Program Committee*

Department of Astronomy, University of Southern California, Los Angeles
7: 1947 April 1

President of the Society: ARTHUR S. KING, Mount Wilson Observatory, Pasadena 4, California

Secretary of the Society: OSCAR E. MONNIG, 1010 Morningside Drive, Fort Worth 3, Texas

VARIABLE STARS

Variable Star Notes from the American Association of Variable Star Observers

By LEON CAMPBELL, Recorder

Variable Stars in Milton Bureau Fields: With the recent issue of *Harvard Annals* 115, Numbers 5 to 11, we have the first extensive publication of the results of the intensive photographic study of variables by the Harvard Milton Bureau. These seven numbers are part of Volume 115, and the whole contains much new and valuable data on several hundred variables. Of the 54 fields studied, the results obtained in eleven are given in this volume, reaching from the South Pole —Field 54—to Field 44, located between 20^h and 22^h, and —15° to —45°. The stars selected for study included all named variables brighter than the tenth photographic magnitude at maximum, and with ranges greater than a quarter of a magnitude.

In using the material on the long-period variables, the estimates of brightness were grouped in 10-day means, conforming to the practice long in use for the visual estimates of the same stars. Dates of maxima and minima of these particular variable stars were read from the plotted curves, usually to the nearest five days.

As in the case of the long-periods, numerous details are given for the semi-regular and irregular variables. In many instances periods, or at least cycles, have been derived. Plotted light curves for many of the long-periods, semi-regular and irregular variables are shown throughout the volume.

Less detailed data are given for Cepheids and eclipsing stars, mainly facts as to revised periods, ranges, etc.; it being the intention of the authors, Drs. Cecilia Payne-Gaposchkin and Sergei Gaposchkin, to treat these stars more exhaustively in a later publication. Mean light curves are tabulated and in some instances illustrated for the Cepheids. Miscellaneous variables are studied in as small or large detail as the occasion demands. Mention is also made of those stars which were found not to be appreciably variable.

Besides the Drs. Gaposchkin, who were mainly responsible for the planning of the program, the making of observations and the general discussion, some thirty persons took part in the work, mainly as observers, computers, and recorders.

In the numbers now reviewed there are represented 210,000 observations on 342 variables; 94 of these variables are of long-period, 82 of semi-regular or irregular type. There are 69 eclipsing stars, 62 cepheids, and 35 miscellaneous variables, including 6 novae.

Some details concerning special fields and variables are of interest. Each field is 30° square, with centers at 0°, 30°, 60°, and 90°, north and south declination. In all of the fields are numerous long-period variables which have been for many years under close scrutiny by visual observers. In very few cases do the periods derived from the photographic data differ materially from those derived from visual observations. With the enumeration of the dates of maxima and minima, one has the material for studying any possible changes in period which have occurred in the stars since the turn of the century. In general, the observations of the long-period variables extend from 1900 to 1941.

Theta Apodis, long suspected of variability, although somewhat unsatisfactory to observe because of its brightness, is confirmed as a variable, with a suggested period of 119 days. This star, along with U Mensae, is classed as a semi-regular variable.

W Indi, previously considered a long-period variable, should doubtless be relegated to the semi-regular class. The average period is 199 days, but it is far from constant. RR Telescopii should also be put into the semi-regular rather than in the long-period class.

The study of the cluster-type variable, S Arae, confirms a definite change of period, as noted by previous observers.

Kappa Pavonis has been very thoroughly observed and discussed. The changes in period and in form of light curve, previously noted by visual observers, are well confirmed by the photographic observations. A plot of the dates of primary and secondary maxima of R Centauri confirms a tendency to a change in period found from the study of the visual observations.

Field 50 ($10^h\,30^m$ to $13^h\,30^m$ and $-45°$ to $-75°$) appears to be richer in bright Cepheids than any other equal area of the sky, 28 falling within the scope of the program. Field 49 is remarkable for the large number of long-period variables with periods of around 400 days.

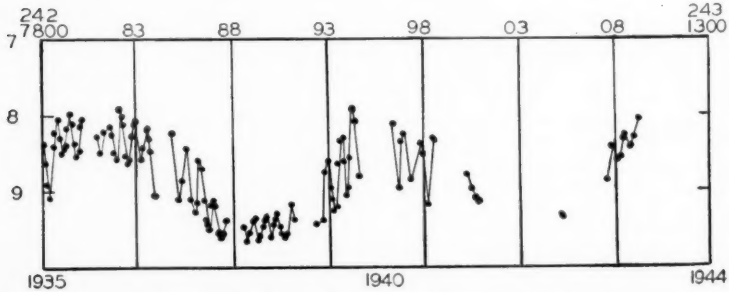
Z Velorum, a long-period variable with a mean period of 425.2 days, is evidently slowly changing the length of its period.

R Pictoris is definitely to be placed in the semi-regular class, not in the long-period class.

A fairly complete photographic light curve of Nova Pictoris, covering the years 1925 to 1944, is illustrated, together with a curve of the visual observations. The agreement is remarkably close except for the year 1929, when the photographic curve shows a marked increase in light at about magnitude 6.5.

In spite of the fact that Z Aquarii shows emission lines in its spectrum, the star must be called semi-regular, and not a long-period variable.

With this study of eleven fields out of the 54 scheduled, it looks as though well over a million observations will eventually be discussed on nearly 2,000 variable stars.



PHOTOGRAPHIC LIGHT CURVE OF —CARINAE, —63° 1126

Double Period Variables: In these Notes for October, 1946, attention was called to the double period variable discovered by Reverend Daniel O'Connell. A recent publication of the Riverview College Observatory in Australia contains detailed observations and a light curve of the star as observed from photographs during the years 1935 to 1946. A plot of the observations under 10-day means is shown in the chart, covering two of the long-term maxima, and a long-term minimum. It will be noted that the star follows the pattern of several other variables of this double-period type, with greater range at maximum and a very small amplitude at minimum. The star would be a very desirable condidate for continuous observations by visual methods. The short term period is 67.5 days and the long term about 1,500 days, or four years. The star should now be at long-term maximum.

RY Sagittarii: This star was reported by de Kock of Capetown as of magnitude 13.2 late in February, with a drop of five magnitudes in 20 days.

R Coronae Borealis: This star is back to normal maximum brightness, after having spent five months passing through a deep minimum.

Gamma Cassiopeiae: Among the peculiar bright variables is Gamma Cassiopeiae, which is not only a suitable case for observations by the variable star observer with little or no optical equipment, except his own eye, but is also an important star to be observed rather continuously, if we are to keep well informed concerning its variations. Since last November, the star has increased in brightness from a minimum, at magnitude 3.0, to 2.6.

Observations received during March: A total of 2,763 observations were received in March from 49 observers, as follows:

Observer	No. Var.	No. Ests.	Observer	No. Var.	No. Ests.
Ahnert, P.	39	280	de Kock	75	329
Ashbrook	6	14	Liller	14	14
Bappu, M. K. V.	50	160	Luft	4	22
Bogard	14	35	Matthews	23	202
Boone	7	7	Mount	3	3
Brennan	2	2	Oheim	20	20
Buckstaff	8	8	Oravec	48	148
Chandra	110	141	Parks	23	23
Chassapis	28	45	Peltier	96	122
Dafter	6	38	Petzold, H. R.	11	68
Damkoehler	3	8	Raphael	10	31
Darnell	1	3	Reeves	1	1
Davis	3	24	Renner	50	74
Elias	16	27	Robinson	7	12
Epstein	7	16	Rosebrugh	22	118
Escalante	82	118	Sherman	9	32
Estremadoyro	1	1	Slemaker	10	23
Fernald	105	176	Stahr	1	3
Garneau	17	17	Swaelen	6	12
Harris	6	6	Tarbell	5	42
Hartmann	115	118	Thomas	23	42
Hiett	4	7	Topham	19	21
Howarth	16	17	Welker	10	10
Kelly	12	13	—		—
Kilby	12	12	49	totals	2,763
Kitley	41	100			

April 15, 1947.

Comet Notes

By K. AA. STRAND

Two new comets have been announced during the past month. The first one was discovered independently by Mr. Bester of the Boyden station of the Harvard Observatory in South Africa on March 24 and by Rondanini of the University Observatory in Montevideo, Uruguay, on March 26. At the time of discovery the comet was of the 11th magnitude and diffuse, without a nucleus. Having a declination of —60° at the time of discovery and having at present a southward motion it must be left in the care of observatories in the southern hemisphere. On April 8 the central bureau transmitted the following parabolic elements computed by Dr. J. Bobone at Cordoba, Argentina:

Perihelion time:	1947 May 20.918 U.T.
Longitude of node:	353° 15′
Node to perihelion:	303° 29′
Inclination:	39° 25′
Perihelion Distance:	.5616 astr. units.

The second new comet was discovered on March 27 by Dr. R. Becvar at the Skalnate Pleso Observatory in Czechoslovakia. The position was:

1947 March 27.85417

Right ascension: $19^h\,30^m5$; Declination: 81° 47′
Daily motion: 41^m east; 2° 30′ north
Magnitude 9; diffuse object with no nucleus.

Sufficient observations have been made of this comet to enable Dr. Cunningham of the Students' Observatory, Berkeley, to compute the following parabolic elements:

Perihelion time:	1947 May 3.971 U.T.
Longitude of node:	322° 35′
Node to perihelion:	182° 25′
Inclination:	128° 58′
Perihelion distance:	0.9609 astr. units.

The Periodic Comet 1947 *a* (Grigg-Skjellerup) was finally rediscovered independently on March 11 by Giclas at the Lowell Observatory and Johnson at the Union Observatory in South Africa. It was found to be a diffuse object of approximately 11th magnitude without a central condensation. The observations showed that the ephemeris was 5 minutes off in right ascension and 5° in declination. This is the reason that the search for it with the 24-inch Yerkes reflector with its small field was unsuccessful as mentioned in the last report. Dr. Cunningham has revised the elements given by F. R. Cripps, moving the time of perihelion passage up from April 20 to April 18 together with a slight change of the eccentricity. The comet was observed here last on March 18 and is now too close to the sun to permit further observations, but it should be easily observable again in May.

Comet 1946 *k* (Bester) will be observable again in May. The ephemeris was given in last month's report.

The Periodic Comet Schwassmann-Wachmann (1925 II) and Comet 1946 h (Jones) are still well observable. Ephemerides for both these objects were given in last month's report.

Williams Bay, Wisconsin, April 10, 1947.

General Notes

The Rittenhouse Astronomical Society, of Philadelphia, held its monthly meeting on April 11, 1947, in the Fine Arts Building of the University of Pennsylvania. The speaker was Dr. Samuel Barton of the Flower Observatory of the University of Pennsylvania, who spoke on the topic, "The Moon." The address was illustrated with lantern slides.

Amateur Astronomers

In the issue of *Coronet* for April, 1947, appears a five-page item under the heading "Heaven is their Hobby," which gives an account of the work being done by amateurs in astronomy, mentioning some few amateurs by name. The work of the A.A.V.S.O. and of the American Meteor Society is described briefly. Attention is called to the large number of amateurs who have as their principal hobby the making of reflecting telescopes.

The Cleveland Astronomical Society

Dr. J. A. Hynek of the Perkins Observatory addressed the March 7th meeting of the Cleveland Astronomical Society. His topic was "Astronomy from Above the Earth's Atmosphere."

Dr. Hynek was present at the first night launching of a Navy V-2 rocket at the White Sands Proving Grounds, New Mexico, on December 17, 1946. This rocket was 47 feet long and weighed 14 tons. It carried some 2000 pounds of scientific equipment. The rocket reached an altitude of 114 miles and its greatest velocity was almost one mile per second. Its velocity was determined by the Doppler effect, not on light waves but on radio waves.

A great number of scientific data were obtained during the flight of the rocket. Twenty-two radio channels were sending simultaneously the readings of the various instruments. These signals were received and recorded by special receiving equipment on the earth. A motion picture camera filmed the earth as seen from the rocket during its ascent.

The lecture was well illustrated with lantern slides and motion pictures of the launching of the rocket. The motion pictures taken from the rocket were also projected. They showed the edge of the earth and as the rocket rotated it almost gave one a feeling of watching the earth rotate from a distant point. A spirited question period followed the lecture.

The speaker explained how artificial moons might be placed around the earth. If we send up a rocket at just the right velocity, and at a distance of 22,500 miles from the earth give it a horizontal push by an explosion from the side, the rocket will become a moon with a period of revolution equal to the period of rotation of the earth. If the initial push is given in the right direction the rocket will remain above the same spot on the earth indefinitely. The speaker then speculated on the advantages of an observatory on such a rocket-moon well above the atmosphere.

HENRY F. DONNER.

Western Reserve University, Cleveland 6, Ohio.

A Portable Planetarium

With large planetariums now in operation in several of our large cities, many persons have become familiar with them. Compared with these elaborate installations a portable planetarium, to which our attention has been called recently, is, indeed, a novelty. The two, however, have one purpose in common, namely, to enable people to become familiar with the starry sky.

The portable model might, indeed, be called a pocket model. It consists of a sheet of card board which can be folded so as to occupy a very little space. When unfolded and shaped as indicated by appropriate scoring it becomes a square parallelopiped, opened at the bottom with top corners truncated. It is about seven inches high. The shape is such as to lend itself fairly well to delineating the stellar configurations. Being easily movable, it can be tilted and oriented so as to represent the stars at any time of night, for an observer within a certain restricted latitude.

This device has been developed by Mr. William C. Green of Barrington, Rhode Island, whose interest in astronomy is of many years standing, and he is now using his own planetarium to instruct his children in that subject.

Book Reviews

Publications Received.—The publishers of POPULAR ASTRONOMY hereby acknowledge receipt of the following named publications and express their great appreciation and courtesy shown on the part of those who have sent them.

Harvard Reprints:
Nos. 273, 274, 275, 276, 277, 278, 279, 280, 281, 282, 283, 284, 285, 286, 287, 288, 289, 290, 295.

Harvard Reprint Series II:
Nos. 11, 12, 13, 14, 15.

Annals of Harvard College Observatory:
Vol. 110, Addenda.
Vol. 115, Nos. 1, 5.
Vol. 116, No. 1.

Contributions from the Mount Wilson Observatory:
Nos. 708-717.

Annales de l'Observatoire de Paris, Section d'Astrophysique, à Meudon:
Tome VIII, Fascicule III.
Tome IX, Fascicule I.

Observatoire de Paris, Section d'Astrophysique, à Meudon:
Volume I, Fascicule VII.

Stockholms Observatorium Meddelande:
Nos. 56, 57.

Contributions from the Lick Observatory Series II:
Nos. 10-15.

Bulletin of the Geological Society of America:
Vol. 54, pp. 401-456.
Vol. 57, pp. 707-726.
"Origin of the Moon and its Topography" by Reginald A. Daly.